PRINCIPLES OF INTERCHANGEABLE MANUFACTURING

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A TREATISE ON THE BASIC PRINCIPLES INVOLVED IN SUCCESSFUL INTERCHANGEABLE MANUFACTURING PRACTICE COVERING DESIGN, TOLERANCES, DRAWINGS, MANUFACTURING EQUIPMENT, GAGING AND INSPECTION

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PREFACE

WHILE many articles dealing with various phases of interchangeable manufacturing have appeared from time to time in the technical press, no complete and comprehensive treatise dealing with this subject as a whole has heretofore been available to those interested in interchangeable manufacturing in the machine building and metal working fields.

The development of interchangeable manufacturing is closely interwoven with many distinctly American manufacturing methods and processes. Every large American industry has contributed its share to the progress made in interchangeable manufacturing. Different plants working along independent lines have often achieved the same results by widely different methods. The author has attempted to define and emphasize the underlying basic principles, using specific methods only when necessary to illustrate the application of these principles in actual manufacturing processes. He has gathered the information upon which this treatise is based from many manufacturing plants, both large and small, in this country and in Canada. He has seen every method discussed in successful operation, some in one plant, some in another—but not all in any one.

In arranging the material available on the subject of interchangeable manufacturing, the author has first taken up the general principles involved in the industrial application of this method of production, and has then devoted a separate chapter to the definition of the terms used, so that there will be no misunderstanding as to the meaning of the terms used later in the book. The influence of interchangeable manufacturing processes on machine design and the purposes of models are then dealt with, followed by a complete

and minute discussion on the dimensioning of drawings intended for use in interchangeable manufacturing. This is followed by a discussion of the principal elements that govern mechanical production, the equipment required for interchangeable manufacturing (including machines, jigs and fixtures); the gaging equipment necessary; and the principles of inspection and testing. Special chapters are also devoted to the manufacture for selective assembly, and methods used in small quantity production on an interchangeable basis. An entire chapter deals with the service factor in interchangeable manufacturing, because in the final analysis no manufactured machine or device is ever purchased for itself alone, but is acquired for the service which it is supposed to render.

The Pratt & Whitney Co., Hartford, Conn., with whose cooperation this treatise is written, submits it to the public as a part of the company's contribution to the art of interchangeable manufacturing with the hope that it will assist manufacturers and mechanics to employ effectively the principles of interchangeable manufacturing and to reap the benefits that a rational application of these principles make possible. The author also wishes to acknowledge at this time the assistance that has been given him by many other manufacturing plants that he has visited. To name them all would mean a long list of prominent plants manufacturing machine tools, automobiles, tractors, ordnance, typewriters, watches, phonographs, instruments, etc.

EARLE BUCKINGHAM

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CHAPTER I

PRINCIPLES OF INTERCHANGEABLE MANUFACTURING

INTERCHANGEABLE manufacturing consists of machining the component parts of a given mechanism in the manufacturing departments within such limits that they may be assembled in the assembling department without fitting or further machining. Component parts may also be replaced or transferred from one mechanism to another without detriment to the functioning and without machining. The advantages of such a method of manufacture are self-evident, and need not be dwelt upon further. It is obvious that with proper equipment and control, the component parts of a mechanism can thus be manufactured in large quantities at a low direct labor cost.

Economy of Interchangeable Manufacturing. In all private industrial enterprises ultimate economy is the controlling factor of any method of procedure. This does not necessarily mean that the methods adopted always are actually the most economical. Methods which will promote this economy are, however, the ideals toward which manufacturers are constantly striving. Now, a careful analysis will show that interchangeability does not always result in ultimate economy. In such cases the attempt to maintain it is a fault, not a virtue.

To make this point clear, consider the matter first from the standpoint of production alone. The equipment and preparation necessary to produce interchangeable parts are expensive. In making only a small number of special mechanisms, it would be gross extravagance to maintain any high degree of interchangeability. Viewed simply as a question of production, the

problem of interchangeable parts is solved by establishing a balance between manufacturing and assembling costs, whether the quantity of production be great or small, whether the mechanism involved be a standard or a special product.

Ultimate economy, however, must include the factor of service. Suppose automobiles, typewriters, sewing machines, or sporting rifles are sold. Parts will wear out or be broken by accident. The maintenance of service stations, where extra parts are quickly available, tends to keep customers satisfied. Service stations will be least expensive if the product is truly interchangeable and the agent can replace a part with the aid of a screwdriver or wrench — or, still better, if the customer can replace it himself. Since the advent of the automobile, people have been much more interested in things mechanical than before, and have taken pride in making their own repairs. The more nearly interchangeable mechanisms are made, the more this desirable trait is fostered and the less will service stations cost. Ultimate economy, then, requires that service costs be balanced against total productive costs.

Degree of Interchangeability Desirable. It should not be assumed from this that entire interchangeability or none at all must be had. In almost every mechanism certain parts are begun as separate units in order to simplify the manufacture, but are later permanently assembled into a single unit and machined to completion as such. In many such cases, the expense of attaining interchangeability would be too great to justify the attempt, because of the many mechanical difficulties to be overcome. It would be more economical, in case of breakage, to discard and replace the entire assembled unit. In other cases, the functional requirements may be so severe that a system of selective assembly will prove to be the proper course, although this entails carrying a double or triple number of spare parts in service stations, or involves some fitting when replacing unserviceable parts.

In general, however, interchangeability is a desirable goal, and is readily attained in the majority of cases if the proper attention is given to the basic principles governing it, including

the design of the mechanism and the process of manufacture; yet it is limited in several directions by the inadequacy of many present manufacturing conditions. With improved facilities, it may be that in future years a much greater degree of interchangeability will be possible than at present.

The following paragraphs, which are based on manufacturing conditions as they now exist, trace the progress of a commodity through all stages of its manufacture, from its inception as a mechanical project to the final testing that determines its successful completion. An attempt has been made to single out for special comment those factors which make possible, or promote, the interchangeable manufacture of its parts.

Design as it Affects Success. The development of any new mechanism starts with a mental conception of some function to be performed. This conception then takes detailed form, first mentally, then on paper, and finally in metal. The experimental model — if such be constructed — is usually made by the cut-and-try method. Little attention is paid in the beginning to future manufacturing requirements. The main object is to construct a mechanism that will function properly regardless of the exact design. When this end is reached, what may be called the inventive or functional design has demonstrated its success.

Before manufacturing is begun, however, a manufacturing design must be perfected which will modify the inventive design so as to allow its economical production on a large scale. Several manufacturers recognize this twofold nature of designing, and maintain a separate department for each type. Indispensable as is the original invention, it is the manufacturing design which largely determines the success or failure of a given project. This manufacturing designing necessarily continues throughout the whole course of production because of the almost infinite number of petty detailed questions involved, only a few of which can be foreseen and answered in advance. One of the important functions of an engineering department is to keep in close touch with the progress of the work in the shops, deduce general principles therefrom, and apply these

principles not only to the work in hand, *but also to all new work* that may be developed.

The Manufacturing Model. Assume that the functional requirements of the mechanism are established and that the manufacturing design has been adopted. The first concern is to test this design as far as possible. The most certain method of accomplishing this is to develop a physical model. Such a model must not be confused with the experimental model, as its purpose is quite different. The experimental model shows that the mechanism will perform certain functions. The manufacturing or physical model, if properly developed, proves that the mechanism, as modified and developed to facilitate manufacture, still retains the functional advantages of the experimental model. The manufacturing model is naturally an expensive piece of equipment, but if a large output of a new commodity is under consideration, it is money well invested. In the case of a small total output, a "pilot" mechanism is often built for this purpose, which is not set aside for future reference but incorporated in the product itself.

There are many other services which a manufacturing model is capable of rendering. It may serve as a physical standard of dimensions for the future product. In this case, it must be made with much greater care than if it were to be used merely to test the functioning of the manufacturing design. Such a model will be of great value as a reference at all times during production. In itself, it comprises an effective functional gage to test any completed part. It should be used but rarely, however, for that purpose. In addition, the component parts of the model are of great assistance in checking the manufacturing equipment in the early stages of the work.

Clearances. Clearances are vital factors in interchangeable manufacturing. Fits can be secured without interchangeability, but the latter cannot be maintained without proper clearances. It is self-evident that a certain space must be left between operating parts. The minimum clearances should be as small as the assembling of the parts and their proper operation under service conditions will allow. The maximum clearances should

be as great as the functioning of the mechanism permits. The variation between a maximum and a minimum clearance determines the manufacturing tolerance. It is clear, then, that determining at the outset the permissible clearances establishes also the extent of the tolerances which control the final inspection.

Clearances should be one of the principal considerations in developing the manufacturing design. This design should aim to allow the greatest possible amount of clearance between companion parts. The more the design lends itself to this end, the greater the economy of manufacture and the greater the degree of interchangeability obtainable. In determining which parts of a mechanism can be made interchangeable, this matter of permissible clearances plays the largest part. A mechanism which is so designed that it cannot permit fairly liberal clearances is not a suitable one to be manufactured on a strictly interchangeable basis with the standard equipment now available. Every operating part of a mechanism must be located within reasonably close clearances in each plane. After such requirements of location are met, all other surfaces should have liberal clearances, unless the factor of strength is the controlling one.

Manufacturing Tolerances. The general tendency in the past has been to establish manufacturing tolerances by trying to hold the product as closely as possible to a fixed size. The natural result of this policy is that the tolerances established on paper are often exceeded; yet the actual working variations remain unrecorded, because it is argued that under certain conditions the original requirements might be met and, therefore, the tolerances noted are the proper ones, even though they are not maintained. Every effort to make the recorded tolerances represent the actual working tolerances is opposed on the ground that such a procedure would lower the shop standards. As a matter of fact, it is hard to understand how anything could lower the standards of the shop more than the absolute disregard of the rules it is supposed to be obeying.

There is a further argument for the acceptance of liberal tolerances. Too often in manufacturing concerns, and especially in the case of interchangeable manufacturing, one finds details

being made ends in themselves rather than means to a larger end. In producing a component part, the main object should not be to demonstrate how closely a fixed size can be approached; the aim should be to construct, as economically as possible, a mechanism that will satisfactorily perform certain functions. The knowledge of how accurately a machining operation can be performed is indeed invaluable in making the manufacturing design; but when that design has once been completed, interest should shift to the proper functioning of the completed mechanism. Finally, it may be said that in most cases the tolerances originally fixed are increased during the process of manufacturing without detriment to the mechanism. It is rarely that a tolerance has to be reduced.

The proper minimum clearances can be determined quite readily and definitely for most cases in the early stages of the work — the manufacturing model is of great value in this respect — but the maximum clearances become established only after extended experience with the particular mechanism. In many cases the extreme maximum is never found, because long before that point is reached, the tolerances have become so liberal that there is no need, from the standpoint of economical production, to increase them further.

Component Drawings. Component drawings have two main functions to perform. The first is to give such information about the design and the tolerances that the manufacture of the product can begin. This does not seem like a very difficult task, but the notation of the tolerances on component drawings has created new problems of interpretation that have not, as yet, been fully solved. At the present time, the language of drawings is not altogether clear and exact.

The first tendency in introducing tolerances on drawings seems to have been to attempt to express a permissible variation on every dimension given. The results obtained in the shop depend, then, upon the particular combination of dimensions used. Different organizations using different combinations could obtain radically different results; and of the possible number of different combinations there is no end.

The existence of a tolerance on a drawing is an acknowledgment that variations are inevitable in the physical dimensions of the product. Any dimension given on such a drawing without a tolerance should not be construed to denote an absolute size without error, but rather to indicate either that the permissible variation for that point or surface is controlled by tolerances given on other co-related dimensions, or that the dimension is so relatively unimportant that no attempt had been made to determine its permissible variation.

In making component drawings, the effort should be made to so give the dimensions and necessary tolerances that it would be possible to lay out one, and only one, representation of the "maximum metal" condition and one, and only one, of the "minimum metal" condition. If such lay-outs were superimposed, the difference between them would represent the permissible variation on every surface. Any condition of the product which fell within the zone thus established could be considered as meeting the requirements of the drawing. If one will make a few such lay-outs, it will soon be clear to him that there are always a number of dimensions that should be given without tolerances if drawings are to be kept consistent and intelligible.

Information on Component Drawings. It must be realized at the start that it is impossible in every case to give on one component drawing all the dimensions that are needed to construct the patterns, tools, gages, and other manufacturing equipment, without introducing many inconsistencies. Certain dimensions could be correct if one set of holding points and one series of operations were to be used, but would be incorrect under different conditions. If the component drawings are made so that they represent the proper completed conditions — call them inspection gage requirements if you will — the end in view is attained. Any figures that the shop desires to use are correct if they insure this result.

It is impossible to amplify this point without entering into a prolonged discussion of the effect of using different holding or registering points in the manufacturing processes. Yet it

may be of interest to know that several manufacturing plants solve this problem by adding operation drawings, which give only the specific dimensions required at a particular operation. Some of the dimensions are duplicates of those on the component drawing, while others are computed to serve their restricted purpose. This proves an effective means of recording additional information required in the manufacturing departments, which cannot be put on component drawings without danger of misuse.

After production is well under way, the component drawings have served their first purpose. In the meantime, the actual manufacturing operations have made available a store of new information regarding the proper conditions to be maintained. It should be the second function of the component drawings to record as much of this information as possible. Conflicting information or misinformation should be eliminated at the same time; in short, the drawings should be revised to agree with actual conditions and requirements. It has been a great fault in the past to neglect this second function almost entirely. It is a difficult task to make the component drawings represent from the first conditions that must be maintained. In time, the shop will discover many of them, often after bitter experience, even though they have been omitted from the component drawings. Frequently, however, it happens that this information does not make its way back to the office, but is retained by the shop men among themselves. Often this is the fault of the office, which is prone to consider such information as criticism, so that the shop, after a few rebuffs, makes no further attempt to pass it along. It is most essential, however, that such information be recorded in permanent form, not only because of its value to the work in hand, but also because of its helpful application to new work in the future.

Dimensioning of Component Drawings. The problem of the proper dimensioning of component drawings is strictly a mathematical one. There are a few basic principles in regard to it as fixed and simple as Newton's three laws of motion, but even more difficult at times to apply correctly. When either of the two following principles is violated, trouble will inevitably follow:

1. In interchangeable manufacturing, there is but one dimension (or group of dimensions) in the same straight line that can be controlled within fixed tolerances. That is the distance between the cutting surface of the tool and the locating or registering surface of the part being machined. Hence, it is incorrect to locate any point or surface with tolerances from more than one point in the same straight line.

2. Dimensions should be given between those points which it is essential to hold in a specific relation to each other. The majority of dimensions, however, are relatively unimportant in this respect. It is good practice to establish locating points in each plane, and to give, as far as possible, all such dimensions from these common locating points.

There are also a few other general principles which it is good practice to follow. Although violations of them are not errors in themselves, they lead to many unnecessary errors. In all of this work it must be realized that it is impossible to create anything that is altogether fool-proof; the best that can be expected is to make conditions such that little or no excuse remains for making a mistake. The three following principles are of this order:

1. The basic dimensions given on component drawings for interchangeable parts should be the maximum metal sizes, except for force fits and other unusual conditions. The direct comparison of the basic sizes should check the "danger zone" or the minimum clearance conditions in most cases. It is evident that these sizes are the most important ones, as they control the interchangeability. They should be the first determined and, once established, they should remain fixed if the mechanism functions properly and the design is unchanged. The direction of the tolerances, then, would be such as would increase this clearance. For force fits, such as taper keys, etc., the basic dimensions should be those which determine the minimum interference (which is the "danger zone" in this case) and the direction of the tolerances for this class of work should be such as would increase this interference.

2. Dimensions should not be duplicated between the same

points. The duplication of dimensions causes much needless trouble, due to changes being made in one place and not in the others. It causes less trouble to search a drawing to find dimensions than it does to have them duplicated and, though more readily found, inconsistent.

3. As far as possible, the dimensions on companion parts should be given from the same relative locations. This procedure assists in detecting interferences and other improper conditions.

If careful thought is given to these component drawings, much time and effort will be saved later in the shop. If they are neglected, all the future work will suffer. A large percentage of the mistakes made in the manufacturing departments may be traced back to improper component drawings.

Specifications for Interchangeable Manufacturing. The information that can be included on component drawings, except in the case of a very simple or familiar mechanism, is seldom sufficient in itself to enable the manufacturer to proceed intelligently with a new product. It is desirable that he know the particular purpose for which the mechanism is to be made. The better he is informed on this subject, the greater service he can render in promoting its economical manufacture and future development. Specifications are supposed to supplement the drawings by giving all the needed additional information which has no place on the drawings. I say "supposed" because it is only in rare cases that the specifications commonly encountered give all the desirable information. They usually deal with only the most exacting requirements and make no mention of the others, thus establishing a severe precedent for the solution of all questions in regard to the requirements, important and unimportant. They seldom indicate the essential object in view, namely, the economical production of mechanisms which will function satisfactorily.

Specifications should state the end to be accomplished, and should give all possible information to assist in the attaining of that end. Any unusual conditions should be explained in detail. All exacting requirements should be specified with the reasons

for the same, including requirements of functioning and of materials to be used. But they should not stop here. The less exacting conditions should be noted also. If a certain material is specified, and the chief consideration is economy, it should be so stated, with the substitution allowed. The material that might be most economical under one set of conditions might be otherwise under different circumstances. Parts which are detailed on the drawings but for which commercial articles can be substituted should be so designated. The specifications should list those parts which must be made interchangeable and those which need not be. A description of the tests for materials, for physical dimensions, and for functioning should be included. In fact, any information that will assist in the manufacture of the product should be given. Some of it will specify the results to be obtained; more of it should be information to assist the manufacturer, not hard and fast rules which he must follow regardless of consequences.

Such specifications would undoubtedly be far from complete at first. Provision should be made to keep them abreast of the actual progress of the work. The shop should use them as a place to record as much of the experience gained as possible. If certain methods have been found unsatisfactory, here is an ideal place to record the fact, and perhaps save a duplication of the mistake in the future. If other methods have proved satisfactory, they, too, should by all means be recorded. In fact, specifications of this kind, although they would in time become voluminous, would be a history of a mechanism and furnish valuable data to assist in developing new mechanisms.

Written specifications are held in low esteem by the majority of manufacturers. They do without written specifications for their own products, and when obliged to meet them for contract work, find them an additional annoyance instead of a help. This is due, in large measure, to the fact that this subject, as also the matter of tolerances, has been regarded as an end in itself instead of as a means to a larger end. Manufacturers do have specifications, although they are seldom called by that name and are seldom written or grouped together for ready

reference. Some of them may be found in the cost and production records, some in the shop correspondence, but most of them are carried in the memories of the foremen and older employes who maintain the traditions of the shop.

Gages for Checking Results. Thus far those elements which form the groundwork for actual manufacturing operations have been discussed. The manufacturing design has been developed; it has been tested with the manufacturing model; the first guess as to the proper manufacturing tolerances has been made; all suitable and available information has been recorded on the component drawings; and the specifications to supplement these drawings have been partially developed by recording there all further information available that will assist in accomplishing the main purpose, namely, to produce satisfactory mechanisms as economically as possible. The means of carrying on the work of actual production and the facilities that should be provided for checking the results, must now be considered.

There are two important reasons for inspecting the product during manufacture: First, spoiled parts must be eliminated as soon as possible to save the expenditure of useless effort on unserviceable pieces. Second, the completed components must be checked before assembly to eliminate the unserviceable parts and thus insure the proper functioning of the mechanism. For these purposes, gages are extensively employed.

A gage should be provided whenever its use is more economical than the use of standard measuring instruments. For example, if the total production of a certain mechanism amounts to about a dozen units, it is extravagance to provide special gages. On the other hand, if this production amounts to several thousand units, a complete set of gages is both desirable and necessary. The extent to which gages are necessary, therefore, depends in great measure upon the amount of the total production. Furthermore, gages should be provided to check only those conditions which it is essential to maintain. The nature and extent of the gages required depend upon the manufacturing conditions. In many cases, a check on one or two points is sufficient to detect

any unsatisfactory results. Under varying manufacturing conditions different faults must be guarded against. Gages are a preventive and not a cure. The point to be emphasized is that they should be provided whenever their addition will result in the production of more or better components with a total expenditure of the same or less effort.

Main Classes of Gages. There are two kinds of gages to consider, which, for want of better terms, will be called limit gages and functional gages. A limit gage is one that checks a specified dimension to specified tolerances. A functional gage is one that checks the relationship of several dimensions to insure the proper functioning of the assembled mechanism. As with other manufacturing equipment, the exact design of a gage is unimportant, if it fulfils its purpose simply and efficiently.

The degree of accuracy or precision required depends upon the extent of the tolerances. In all cases, on limit gages, the variation must be inside the established limits of the component. The dimensions given on component drawings are limit gage sizes. For example, the limits given for the diameter of a stud should be interpreted to mean that such diameter must be made to satisfy ring or snap gages of the sizes specified.

As yet master gages, or reference gages, as they are variously called, have not been touched upon. A master is a physical standard of size or form used for reference purposes. It is needed only where the degree of precision required is so exacting that the errors inherent in direct measurements with standard measuring instruments will be great enough to prevent the proper functioning of the product. If a manufacturing model is carefully developed, few, if any, masters will be required. For simple dimensions of length, it is usually sufficient to establish reference pieces of, say, tenth-inch units. For important functional contours, masters are essential.

Test pieces for individual gages are necessary only when the amount of gage checking is so great that too much time is consumed by using standard measuring instruments, or when no skilled labor is available for this checking. Test pieces are therefore desirable for checking complicated profile and fixture

gages that receive hard usage, but they are seldom necessary for plain plug, ring, and snap gages.

Manufacturing Equipment. Suitable tools and equipment with which to manufacture a product must also be provided. The first logical step to this end is to make operation lists, planning in detail the successive operations, and specifying the type of machine, fixture, tool, and gage required. These operation lists are an integral part of the specifications, subject, of course, to such modifications as are found necessary. Of the machines themselves but little mention need be made at this time. Standard machine tools are now on the market for making almost every variety of machining cut. Special machines are required only for very unusual operations or for extremely large productions where many automatic operations are performed.

The design of the fixture and the tool depends to a great extent upon the design of the piece to be machined. Great care should be taken to maintain the same locating or registering points in the fixtures as are used for the gages. The ideal condition is to have the registering points for both fixtures and gages identical with the points on the component drawings from which the surfaces in question are dimensioned. After the equipment is complete, the component drawings should be checked and revised where necessary to obtain this result.

Another factor which must be considered in the design of the equipment is the required rate of production. In the case of a small output, the cost of the equipment amounts to a large percentage of the total cost of production. As the output increases, the proportionate cost of the equipment decreases, thus making it desirable to refine this equipment, if by so doing the production can be increased with the expenditure of less productive effort. Here, as elsewhere, it is a question of balancing the cost of one item against that of another and of selecting the most economical combination.

In most cases, except with some automatic machines or on very large work, the operator spends more time in handling the work than the machine takes to perform the machining operation. Therefore, whenever the rate of production is high enough to make

it economical, the fixtures should be made for rapid operation, even though this greatly increases the initial cost of equiqment.

Production Problems. The actual production consists of taking the raw material and passing it through the equipment until it emerges as a finished component. The production problems are many and varied. Any part of the preceding work which has been slighted or left undone must be completed here in addition to the many tasks which are involved in the production itself. The greatest problem involved in production is that most uncertain factor — human nature. The present tendency is to provide equipment that can be operated by semi-skilled labor. Equipment, however, cannot be made altogether fool-proof. As noted before, the best that can be done is to arrange matters so that little or no excuse remains for making mistakes.

People thoughtlessly speak of unskilled labor. The more this problem is studied, the more it is realized that there is no place in interchangeable manufacturing for such assistance. That is, there is no task so elementary but that better and more economical results can be obtained by a certain degree of training or skill in the operator. An attempt is made to subdivide productive operations into the most elementary tasks so that labor can be readily trained to perform them satisfactorily. Each manufacturer is forced to train the majority of his own operators. Naturally, then, the shorter the time required for this training, the sooner the results will show in the production. On the other hand, the less skill required of the operator, the more elaborate and complete the equipment must be. The amount of supervision required for both operators and equipment is also greatly increased, in both quantity and quality.

In any case, the better the training that these operators receive, the higher is the quality of the work produced. And the matter of honest, serviceable quality as distinguished from mere appearance is more appreciated than formerly. The operator should be taught to maintain the established tolerances. If the specified tolerances prove too severe in practice for economical production, they should be corrected, provided the functional requirements of the mechanism will permit. If they

are not too severe, there is no excuse for violating them. The practice of adhering to the specified tolerances will do much to promote a high quality of product.

Shop Inspection of Product. The inspection and acceptance or rejection of the components falls logically into two divisions. The first is the shop inspection which is made while the material is in process of manufacture. The object is to cull out defective work as soon as possible and also to detect any defects in the equipment that would result in faulty work. If the percentage of rejections is normal, it is evident that the requirements specified and the manufacturing facilities provided are satisfactory. If the percentage is high, it is evidence of improper conditions somewhere which should be investigated, and the trouble should be corrected at its source. Sometimes an error occurs, with the result that the requirements are exceeded on a large number of parts. Such matters should be investigated and settled according to their merits. If the pieces will be serviceable and can be completed without undue cost, the factor of economy will play a large part in the decision. In such cases, the requirements specified should not be changed unless it is evident that such a change will result in an economic benefit in the future. As in all other cases, ultimate economy is the goal.

Final Inspection. The second division of the inspection is the final examination of the completed parts. The object of this inspection is to see that all components which will function properly are accepted and that all unserviceable parts are rejected. This inspection is largely governed by the requirements of the component drawings — often represented by gages — and by the specifications. It is therefore most important that the drawings and specifications give as nearly as possible the limits of parts which will function properly. Yet, as has been already noted, these drawings and specifications are incomplete at the beginning, and probably will always be so, to a certain extent. Therefore, a rigid adherence to the letter but not to the spirit of the drawings and specifications is unwise, as it will not aid in the acceptance of all serviceable material, nor in the ultimate economy of manufacture. In addition to the written require-

ments, inspectors must have a certain amount of education and experience with the mechanisms involved, or with similar mechanisms; otherwise the inspection will always prove a hindrance to the main purpose.

The characteristic needed for a successful inspector is a judicial mind. Since the requirements are laws, the inspection should equitably enforce them. The spirit of the requirements should be enforced in those cases where their exact expression is incomplete. If the essentials are always specified definitely and completely, it will be a fair assumption that incompletely specified conditions are relatively unimportant. Wherever possible, the requirements should be revised to make the letter and the spirit agree, but the attempt to cover every minute and unimportant detail will prove impossible in practice.

The functional requirements should be maintained in the final inspection strictly according to the specified conditions. The non-functional requirements should be handled in a more judicial manner, each case being decided on its merits. As a matter of fact, this final inspection should be in the nature of a functional inspection only. Little attention should be given here to the non-essentials other than, perhaps, a visual inspection for general quality, and some supervision of the shop inspection to see that proper precautions are taken during production to insure a good product. In all cases, the main effort throughout the work should be to establish, define, and maintain the essential conditions first, letting the non-essentials develop in practice. No secret, however, should be made of the fact that these non-essentials are left to work out their own salvation.

Test of Success. The final and complete evidence as to whether the aim has been accomplished is furnished after the mechanisms have been assembled and tested. If the total costs have been reasonable and the completed mechanisms assemble properly and perform satisfactorily all the required functions, it is conclusive evidence that all essentials have been mastered. On the other hand, if the costs are excessive or if the mechanism fails to assemble or to operate properly after being assembled, it is equally conclusive evidence of failure.

CHAPTER II

TERMS USED IN INTERCHANGEABLE MANUFACTURING

In order to describe concisely characteristics peculiar to interchangeable manufacturing, it is necessary to use many words and phrases in an arbitrary sense. Therefore, to avoid misunderstanding, space is taken here to define several of the important terms. The interpretation of these terms is limited to the ideas they express in this treatise.

Interchangeability. The term interchangeability, as used here, refers to absolute interchangeability. In this sense, interchangeable parts are parts that are so made that they can be assembled or interchanged after final inspection without machining or fitting, and any possible combination of these parts will assemble, interchange, and function properly. To insure this end, the most extreme limits permitted must be constantly checked against each other.

Selective Assembly. Selective assembly refers to a method of manufacturing similar in many of its details to interchangeable manufacturing, in which component parts are sorted and mated according to size and assembled or interchanged with little or no machining. Companion parts made to the extreme limits are not supposed to interchange. For instance, a maximum male component will not assemble with a minimum female part. However, the maximum male and female, or the minimum male and female must interchange. A good example of this method of assembling is found in the production of ball bearings. The balls are sorted into groups, according to their size, to facilitate the assembly of any bearing with balls of uniform size. As a matter of fact, nearly every so-called interchangeable article represents a combination of the two methods of quantity production — interchangeable and selective.

Function. The term function is used extensively and with various shades of meaning. The word itself has many meanings. The dictionary gives one as "fulfillment or discharge of a set duty or requirement"; and another as "that mode of action or operation which is proper to any structure," etc. As applied to component parts, the word has been used to express both these meanings. This includes all requirements of interchangeability and service which the part must render throughout the normal life of the mechanism of which it forms a part. The same meaning is intended when it is applied to the assembled mechanism. The functional design refers specifically to the combination of mechanical movements required to make the completed mechanism perform its specified duties. Functional gages are those which test the functional operation of components without strict adherence to their exact physical dimensions.

Limit. In every interchangeable mechanism there are certain maximum and minimum sizes for each part, between which the parts will function properly in conjunction with each other and outside of which they will not. These sizes are the absolute limits of the parts. The established limits are the maximum and minimum dimensions specified on the component drawings. The established limits should approach as closely to the absolute limits as normal manufacturing conditions require. Limits established without regard to the absolute limits result either in excessive cost of manufacture or faulty mechanisms or both. If the established limits are much more severe than the absolute limits, needless expense is incurred in manufacturing. On the other hand, if the established limits are more liberal than the absolute limits, unsatisfactory mechanisms will be produced.

Tolerance. Tolerance is the amount of variation permitted on dimensions or surfaces. The tolerance is equal to the difference between the maximum and minimum limits of any specified dimension. For example, if the maximum limit for the diameter of a shaft was 2.000 inches and its minimum limit was 1.990 inches, the tolerance for this diameter would be 0.010 inch. By determining the maximum and minimum clearances required on operating surfaces, the extent of these tolerances is established.

The application of the tolerances to the basic dimensions fixes the limits.

Basic and Model Size. Obviously, the absolute limits of the various dimensions and surfaces indicate danger points, inasmuch as parts made beyond these limits are unserviceable. A careful analysis of a mechanism shows that one of these danger points is more sharply defined than the other. For example, a certain stud must always assemble into a certain hole. If the stud is made beyond its maximum limit, it will soon be too large to assemble. If it is made beyond its minimum limit, it will be too loose or too weak to function. The absolute maximum

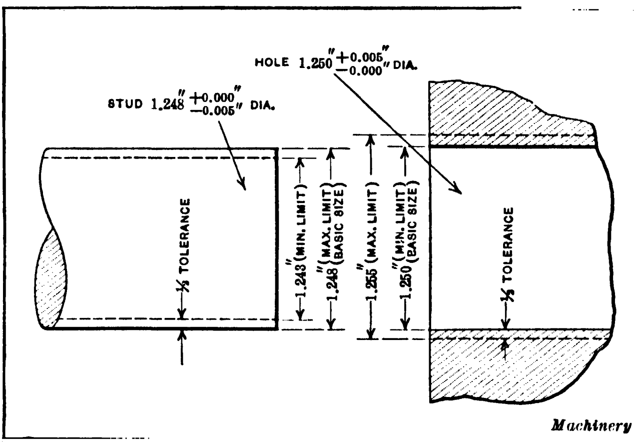


Fig. 1. Graphic Illustration of the Meaning of the Terms Limit and Tolerance

limit in this case can be defined within a range of 0.001 inch, whereas the absolute minimum limit cannot be defined within a range of at least 0.004 inch. In this case the maximum limit is the more sharply defined.

The basic size expressed on the component drawing is that limit which defines the more vital of the two danger points, while the tolerance defines the other. In general, the basic dimension of a male surface is the maximum limit which requires a minus tolerance. Similarly, the basic dimension of a female surface is the minimum limit requiring a plus tolerance,

as shown in Fig. 1. There are, however, dimensions which define neither a male nor a female surface. Such are dimensions for the location of holes. In a few cases of this kind, a variation in one direction is less dangerous than a variation in the other. Under these conditions, the basic dimension represents the danger point, and the tolerance permits a variation only in the less dangerous direction. At other times, the conditions are such that any variation from a fixed point in either direction is equally dangerous. In such a case, the basic size represents this fixed point. Tolerances, when given on the component drawing, extend equally in both directions.

If a model is developed as a standard of precision, the model parts become the physical representations of the basic sizes. In other words, for all practical purposes, the model size and the basic size are identical.

Maximum Metal Size. Maximum metal size is that limit at which the part contains the maximum amount of metal. This would be the maximum male limit and the minimum female limit. In many cases, a careful analysis is necessary to determine which limit represents the maximum metal conditions, as many dimensions are neither male nor female. In other cases, such as locations of holes, there are neither maximum nor minimum metal conditions. With few exceptions, however, the maximum metal sizes are also the basic sizes.

Minimum Metal Size. Similarly, the minimum metal size is that limit at which the part contains the minimum amount of metal. This is the minimum male limit and the maximum female limit, when the dimensions can be so classified.

Minimum Clearance. It is evident that there must be a definite amount of clearance between male and female components which operate together. The minimum clearance should be as small as will permit the ready assembly and operation of the parts, while the maximum clearance should be as great as the functioning of the mechanism will allow. The difference between the maximum and minimum clearances defines the extent of the tolerances. On companion elementary surfaces, the difference between the maximum male limit and the minimum female

limit determines the minimum clearance, as shown in Fig. 2. On composite surfaces, careful study is required to determine which limit should be used. In fact, it is impossible in certain cases to have the minimum clearance conditions at all points at the same time. In general, however, the comparison of the basic sizes of companion parts gives the minimum clearance conditions. The minimum clearance is quite commonly known as the "allowance."

Maximum Clearance. On elementary surfaces, the difference between the minimum male limits and the maximum female limits establishes the maximum clearances. In general, the

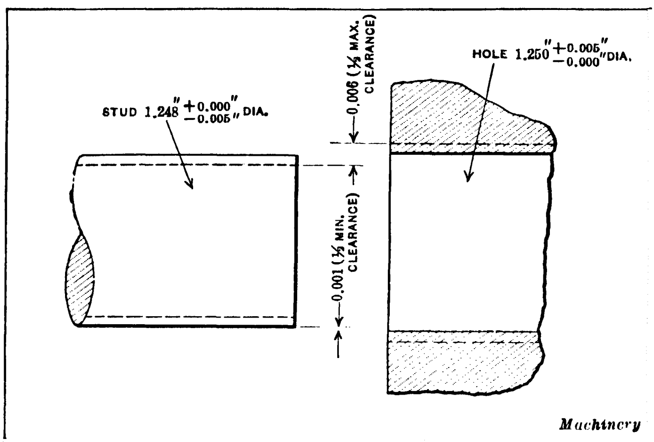


Fig. 2. Graphic Illustration of the Meaning of the Terms Maximum and Minimum Clearance

terms maximum or minimum clearance refer only to the clearance between surfaces which operate together or within close proximity to each other. When surfaces stand well clear of each other, and there is little or no danger of interference, as between unfinished forged or cast surfaces, the matter of maximum and minimum clearance plays little part in determining the tolerances.

Interference. If a male member is larger than a female member, it is obvious that there will be interference when these parts are assembled together. Such interference is required where

force fits are specified. If interchangeable parts are to be forced together, this interference performs a similar function to that of clearance on operating surfaces. In this case, the minimum interference establishes the danger point. This means that for force fits the basic male dimension is the minimum limit requiring a plus tolerance, while the basic female dimension is the maximum limit requiring a minus tolerance. (See Fig. 3.) When the component drawings permit an interference where

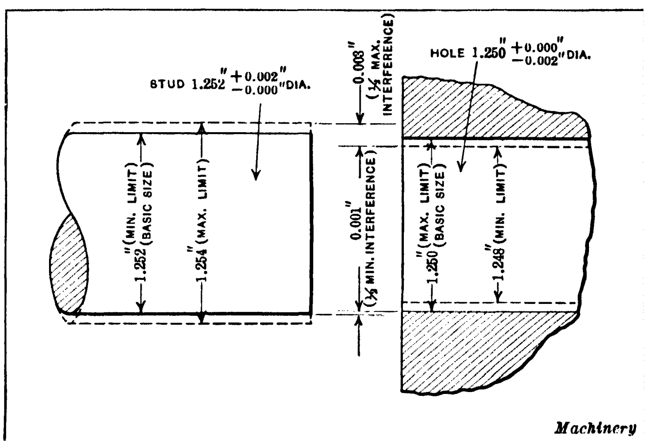


Fig. 3. Graphic Illustration of the Meaning of the Terms Maximum and Minimum Interference

a clearance is required, they are wrong. The term interference is often used to express such conditions of error.

Operating Surfaces. The term operating surface is used to distinguish the working surfaces of the mechanism from the others. It is clear that the working surfaces are the essential ones; all others are present only because of the necessity of holding the mechanism together. Generally speaking, the operating surfaces are the machined surfaces, while the others often retain their original forged or cast finish. The operating surfaces are divided into two classes, which are designated functional and non-functional, or clearance, surfaces.

Functional Surfaces. The functional surfaces are those operating surfaces which control the functioning of the mechanism,

as shown in Fig. 4. These must naturally be held to the closest limits. Every operating part of a mechanism must be controlled in operation within reasonably close limits in each plane. After these functional requirements of location are met, all other surfaces should have as large clearances as possible, unless the factor of strength is the controlling one. Those surfaces that affect the relative location of the operating parts in operation are the functional surfaces. For example, the surface of a pad on which a bracket that carries operating parts is fastened is a

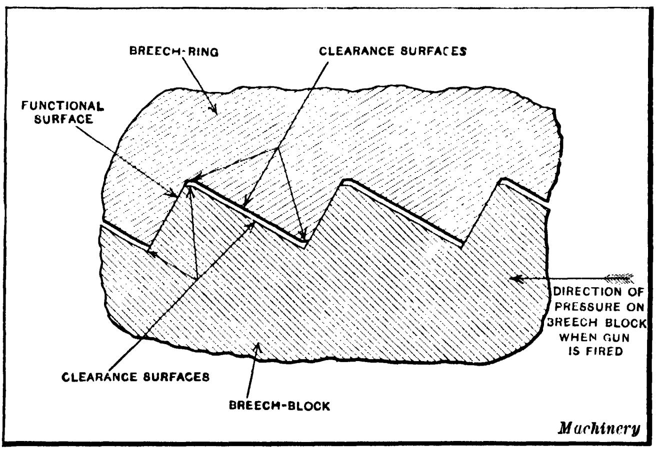


Fig. 4. Illustration showing the Meaning of the Terms Functional and Clearance Surfaces

functional surface; whereas, the surface of a pad that supports a bracket for holding wrenches or oil-cans is not.

Clearance Surfaces. Clearance surfaces are those operating surfaces which are not functional surfaces. In this class are surfaces which do not control the location of operating members while functioning, but which either prevent them from being disassembled or locate them approximately in their inactive position, or both.

Atmospheric Fits. Atmospheric fits, as the name implies, refers to those surfaces which, under all conditions, stand entirely clear of any other operating or functional members of the mechanism. Such is the outside of a machine frame. Many surfaces

on operating parts are themselves also atmospheric fits. With few exceptions, the majority of the surfaces of all mechanisms are atmospheric fits.

Elementary Surfaces. An elementary surface is one which is defined with a single dimension, such as a cylinder, a plane, or a sphere. For example, a reamed hole of a speicfied depth represents two elementary surfaces. The diameter defines one and the depth the other. Obviously, most surfaces which are not elementary in themselves are a combination of elementary surfaces. In so far as such surfaces are machined and measured according to their elements, they are considered elementary surfaces. When the combination as a whole is measured or

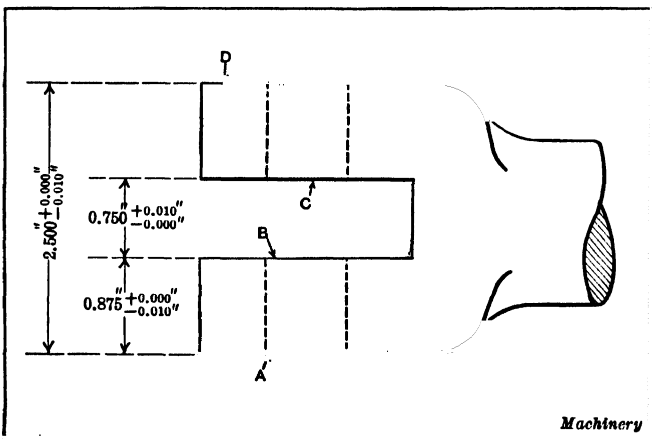


Fig. 5. Illustration showing the Meaning of the Terms Elementary and Composite Surfaces

machined, and a variation on one surface affects the dimension of another, they are not elementary but composite surfaces.

Composite Surfaces. Composite surfaces are those surfaces which are required to maintain a co-relation which cannot be expressed by a single dimension. For example, Fig. 5 shows a yoke end. The over-all dimension (2.500 inches) controls elementary surfaces. The dimension of the slot (0.750 inch) and that of its location (0.875 inch) also define elementary surfaces when used independently. If, however, surfaces marked *A*, *B*, and *C* are required to be checked concurrently, these elementary

surfaces become composite. Irregular profiles, the co-relation of several holes to each other, tapered surfaces, thread sizes and forms, the contour and location of gear teeth, etc., are examples of more complicated composite surfaces than the example shown in Fig. 5.

Compound Tolerances. A compound tolerance refers to those conditions where the established tolerances on more than one dimension determine the required limits. These exist in conjunction with the dimensioning of composite surfaces. For example, a compound tolerance exists in establishing the location of surface *C* in Fig. 5 from surface *A*. This condition of compound tolerances will be covered in greater detail in a subsequent chapter.

Working or Register Points. The working or register points are those surfaces that are employed for locating the parts in the jigs and fixtures during the process of manufacture. Sometimes important functional surfaces are used for this purpose. In other cases, for parts of irregular form, special lugs are provided to serve this end. These are removed after the machining operations are complete. Register points become functional surfaces when they are employed to machine other functional surfaces. As few locating points as possible should be established; this practice simplifies the design of the gages and other equipment.

Unit Assembly. Many mechanisms are a combination of several semi-independent mechanisms which may be assembled and tested individually before they are assembled together. This is known as unit assembly; it is of particular value for a plant which manufactures a varied product where such unit assemblies are interchangeable. An example would be a feed-box that could be used on several types of machines. This practice enables a plant to obtain the benefits of quantity production on these unit assemblies although the quantity of production on any one type of machine is small.

Precision. There are two characteristics pertaining to the physical dimensions of the parts manufactured. For purposes of discussion, they will be called precision and accuracy. The

two are often considered identical, and if ideal conditions could be maintained, they would be identical. In ordinary manufacturing practice, however, precision alone is usually obtained, and precision is all that is necessary in most cases. It is when several factories attempt independently to produce a common interchangeable product that accuracy is required. The degree of precision is measured by the amount of variation that exists between duplicate parts. For example, a reamed hole is dimensioned as 0.500 inch in diameter. In manufacture, a product is obtained in which the difference between the largest and smallest holes produced does not exceed 0.005 inch. The degree of precision in this case would be 0.005 inch, even though the absolute size of the largest hole was 0.508 inch.

Accuracy. The accuracy of any determination is measured by its limits of error from a fixed standard. For example, a length of one inch is to be measured. We will assume, for the sake of argument, that the measuring instruments are absolute. This length measured with an ordinary steel scale gives a result correct within a limit of error of about 0.01 inch. If measured with a micrometer, the result is correct within a limit of error of about 0.005 inch. If measured on a sensitive measuring machine, the result is correct within a limit of error of about 0.00001 inch; while if measured by optical methods, advantage being taken of the principle of interference of light waves, the result is correct within a limit of error of 0.000001 inch or less. It may be of interest to note here that standards of length have been defined by the Bureau of Standards in terms of light waves. By this means, an absolute standard is established, since the lengths of light waves are absolute. The term accuracy implies a comparison with a fixed standard. In the example given to illustrate precision, the limit of precision is 0.005 inch, while the limit of accuracy is 0.008 inch. It is obvious from this that it is more difficult to maintain a limit of accuracy of 0.001 inch than it is to maintain a limit of precision of the same amount.

Component Drawings. Component drawings are detailed drawings of the component parts of a mechanism. For interchangeable manufacturing, these drawings show the completed

dimensions required (or inspection gage requirements) of the parts. These include all tolerances and any sub-assemblies that may be necessary to assist in their proper interpretation.

Operation Drawings. An operation drawing is a detailed drawing or sketch which gives the dimensions required on an individual machining operation. These drawings are used to record much supplementary information that might be confusing or misleading on the component drawings, such as allowances for finishing cuts and grinding operations, etc.

CHAPTER III

MACHINE DESIGN IN INTERCHANGEABLE MANUFACTURING

THE improvement in manufacturing methods and facilities during the past forty or fifty years has been very rapid. Quantity production is now the order of the day. New problems have arisen and old ones must be constantly re-solved to meet the situations thus created. Manufacturing on an interchangeable basis has been a direct development of this advance. The purpose of the present chapter is to discuss the effects of this development on the design of a machine or device, and to emphasize those practices which will promote economical manufacture on an interchangeable basis.

In early days, the design of a new mechanism existed only in the mind of the mechanic engaged in its construction. It was made piece by piece, each detail taking definite shape as it was constructed. The original mechanism was completed, tested, and corrected or rebuilt before the design was finished. Duplicate mechanisms that might be constructed were patterned after the original, and modified or improved as suited the ideas of the mechanics who performed the actual work. Needless to say, interchangeability and quantity production were non-existent factors.

Sketches and drawings were next employed to express the ideas of the inventor, but little attempt was made to indicate more than the general idea and construction. The details of the design and the dimensions of the individual parts were matters for the workmen to decide. A competent mechanic was required to determine these for himself. It was part of his training. Details and dimensions, more or less complete and consistent, made their appearance on the drawings later. Errors and omissions were of little moment, as the mechanic who worked to the drawings expected to select and use the proper infor-

mation given and to ignore the incorrect, supplying all omissions from his own store of mechanical knowledge and experience. The quantity of production was small. Little or no importance was placed on interchangeability. A few workmen thoroughly acquainted with the requirements of the mechanism or with the intentions of the designer performed all the actual work of construction. Under these conditions, functional drawings, which make no pretense of giving more than the general construction or combination of mechanical movements and the general outline of the detailed parts, are sufficient.

Function of Design. Under present manufacturing conditions, with productive operations subdivided into elementary tasks, with productive labor trained along specialized lines, with productive equipment specialized and more nearly complete, with the rate of production greatly increased, with larger organizations in which but few individuals are thoroughly conversant with all the detailed requirements of the mechanism, the design must cover a wider field and be much more comprehensive and accurate. In addition to expressing the ideas of the inventor, it must supply most of the knowledge and experience formerly brought to this work by the mechanic.

We now have, therefore, two types of designing to consider, which we will call the functional design and the manufacturing design. The manufacturing design is a detailed development of the functional design. It corrects and modifies the functional design where necessary, to facilitate the economical production of the mechanism, giving as much as possible of the information previously supplied by the workman. It is evident that the manufacturing design will always be incomplete to a certain extent. Suitable provision for its modification must be made to obtain the advantage of the new and improved methods of manufacture which are constantly developed. Changes, however, in proved manufacturing designs should be avoided when possible. As much or greater care should be taken in adopting changes as is exercised in establishing the original manufacturing design. After equipment has been completed, changes are very costly. A change which might be justified in the early stages of

work often costs more than it is worth in the later stages. This makes it of the utmost importance that grèat care be exercised in the development of the original manufacturing design of a new commodity which is to be manufactured in large quantities on an interchangeable basis.

Classes of Design. For the construction of a small number of special machines, or tools and fixtures, which are built in a general machine shop or tool-room, the functional design is all that is required. The number of men engaged in the production is small, their training is general, and the requirements of the mechanisms can be explained to them personally by the designer as questions arise; therefore, the additional expense of a manufacturing design is not justified. However, in the manufacture of a large quantity of any article, particularly if interchangeability is sought, a complete manufacturing design is necessary. True, this design will work itself out in practice in the course of time, but this is a very slow and expensive method. It means that experimental work on a large scale is carried on, whereas it can be done on a smaller scale with better and speedier results. Furthermore, this method results in continual alterations in the equipment and a loss of interchangeability. However, this chapter is not concerned with designs of special mechanisms, tools, fixtures, etc.; attention will here be given to the requirements of designing as applied to the manufacture of a product in large quantities.

In both types of designing, the end in view is the same as far as the functioning of the mechanism is concerned. This is to develop a product capable of performing certain results which will fill or create a public demand for itself. The means of attaining this are governed by various considerations. For the functional design, any solution is satisfactory. As regards the manufacturing design, the methods adopted must result in ultimate economy. Also, the manufacturing design must resemble the functional to such an extent that all patents will be retained, while those of competitors must not be infringed. This is one of the commercial difficulties that, at times, prevents the true economic development of a commodity.

It is plain that the manufacturing designer must take into consideration every circumstance involved in the production of the commodity. To be successful, he must work in close cooperation with all who will be engaged in the development and operation of the manufacturing equipment. This will include the tool designers, and the superintendents and foremen of the various manufacturing and assembling departments. In general, there is too much detail involved for any one person to carry it alone to a successful completion.

Simplifying Design. When considering the manufacture of a new product, one of two conditions usually obtains. Either it is to be produced in an established plant with an existing variety of manufacturing equipment, or a new plant must be created. In the first case, the designer must be familiar with the available equipment and must modify the functional design so as to utilize these facilities to the best advantage. In the second case, he is not restricted to the use of any specified equipment. In either case, unless the volume of production is to be extremely large with many automatic operations, every effort must be made to reduce the machined surfaces of the various components to simple, elementary surfaces which can be readily machined on standard machine tools with simple, rugged, and inexpensive tools, jigs, and fixtures. If, in the manufacturing design, the component parts are thus simplified, a further advantage is gained. The productive operations on these parts are resolved into simple, elementary tasks, and this simplifies the problem of securing and training the necessary productive labor. Simplicity is a primary source of economy. The number of machining operations is reduced and the direct labor cost thereby lowered. The amount of time that raw material is tied up in process of manufacture is reduced and quicker returns are secured on the money invested in direct labor and materials. The many other economies resulting from simplicity in design, such as lower equipment and maintenance costs are obvious.

Factors Governing Choice of Materials. Those responsible for the manufacturing design must pay close attention to the

character of the materials they specify for the individual components. Ultimate economy is the desired end. This is affected by many different and sometimes opposing factors.

Cost. The first cost of the material is one of these. When several thousand duplicate mechanisms are manufactured, the slightest saving in the cost of direct materials is multiplied over and over again in the course of time. As many parts as possible should be made of the same size and kind of material. This permits purchasing in larger quantities and reduces the gross amount of raw material carried in the store-room. As far as possible, this material should be of standard sizes and forms that can be purchased in the open market at the lowest prices.

Source of Supply. Due consideration must be given to the possible sources of supply for the materials specified. It is a serious matter when production is held up because of lack of material which has a limited or uncertain source of supply. Every effort must be put forth, in making the manufacturing design, to specify materials which are readily secured.

Machining Qualities. The actual economy of low-priced material is governed by the ease with which it can be machined. If a part requires many machining operations, a low initial cost for material is often overbalanced by the greater cost of manufacture. Therefore, if a more expensive material can be machined at a lower cost, ultimate economy dictates its purchase. For this reason, the use of extruded or rolled bars of special form is often adopted in the manufacture of small parts for adding machines, typewriters, counters, and other similar mechanisms.

An illustration of this point occurred in a large plant which makes small duplicate parts. Several of these parts were made of brass castings because of the lower cost of machining, but the price of copper began to rise and was soon about double its normal price. It was decided to substitute cast iron for brass because the difference in the cost of machining was less than the difference in the market price of the materials. Luckily, an investigation was made before the change went into effect. This plant had its own brass foundry but no iron foundry. It was discovered that the foundry had purchased no copper

for several years. In fact, a large stock of pig copper had been stored in a shed and was never touched. Another department of this plant was engaged in making copper matrices by a plating process, and the trimmings from these supplied all the pure copper which the foundry required. This, with scrap brass stock from other departments, made it unnecessary to purchase any metal for the brass foundry in the open market. Needless to say, no change was made in the material of the castings. This incident indicates in some degree the many factors that must be considered to secure genuine economy. It is not a matter of mere addition and subtraction; every existing condition must be taken into account.

Weight of Finished Product. Whenever the weight of the finished product is an important consideration, as with automobiles, etc., the materials used in making it must be of a better grade than when the weight is less important. In every case, the materials specified must be sufficiently strong and rigid to hold their form throughout the normal life of the mechanism. Thus, the detailed design of the various components is governed to a great extent by the nature of the materials which are used in their manufacture. For example, if forged steel is substituted for cast iron, the component will be of much lighter design.

Service Required. The composition of the materials used is governed by the nature of the service which the part must render. One that is subjected to excessive wear must be made of material hard or tough enough to withstand it. Material for parts liable to corrosion or other chemical action must be of the proper composition to counteract it. Material for parts under constant vibration must not crystallize readily. In every event, the materials must be selected to withstand both the use and abuse which they will eventually meet.

It is of interest to note, as an indication of the importance of materials in relation to the total cost of production, that census statistics show that the cost of materials — direct and indirect — is from 30 to 60 per cent of the selling price of the majority of mechanical products which are manufactured in this country.

Clearances and Tolerances. The establishment of suitable clearances and tolerances is a vital, if not the most vital, factor in the manufacturing design. Tolerances are, in many respects, like laws. There are two classes of laws. One is so severe and exacting in its nature that it cannot be enforced, and soon falls into disrepute and is disregarded, even though it remains on the statute books. The other is drawn up with a full understanding of existing conditions, and its justice to all concerned is so evident that it is readily and consistently enforced.

Similarly, tolerances fall into two classes. Those which represent the extreme conditions of accuracy obtainable from the equipment under ideal conditions can be specified without regard to the functional requirements of the product. In such cases they, too, soon fall into disrepute and are disregarded, even though they still remain on the drawings. On the other hand, tolerances are readily and consistently maintained when they represent the widest variations that the functioning of the mechanism will safely permit.

Liberal tolerances and clearances result in easier manufacturing conditions of every sort and thus promote economy; they make quantity production possible. The serviceable life of tools depends directly on the extent of the tolerances. Every exacting tolerance is a direct check on the economical and rapid production of the mechanism. On the other hand, if the functional requirements do not permit wide tolerances, the functional requirements must prevail.

It is evident, then, that the construction must be carefully studied so that the manufacturing design will permit the widest possible tolerances. It is only in exceptional cases that a mechanism cannot be modified so as to retain all functional advantages and yet allow liberal tolerances on the majority of its dimensions. Very often, when there is a severe functional requirement to maintain, the introduction of simple means of adjustment promotes easier manufacturing conditions. In other cases, a system of selective assembly is more desirable.

Applying Interchangeable Principle. The designer must determine which parts will be interchangeable. Interchangeability

can be carried too far and thus allowed to defeat its own purpose as noted in a previous chapter. Interchangeability and liberal maximum clearances are closely connected. Whenever reasonable clearances are out of the question on certain components, these parts are not suitable ones to be manufactured on an interchangeable basis. In this matter, the relative accuracy of the available equipment plays a large part. For example, if the surfaces are elementary and can be finished by a simple grinding operation, much closer tolerances can be economically maintained than if they are composite and require milling or turning operations. The variations on work finished by grinding are about one-third those resulting from milling and one-half those from turning; and the effort expended is no greater. On the other hand, grinding is not always suitable nor possible. Therefore, in determining whether or not certain required conditions permit reasonable tolerances, the designer must consider possible methods of manufacture and must be well informed regarding the normal variations which result from them in actual practice.

This knowledge is the outcome of experience in checking and analyzing results previously secured. This is a matter to which little attention has been paid in the past. For example, in a large and long-established plant, where many milling operations are performed, it had been assumed that these operations were maintained within a tolerance of 0.001 inch. Actual measurements brought out the fact that the normal variation was over three times as great as that, and always had been. A similar misconception of actual conditions was apparent in the majority of shops engaged in government work during the recent war. When their product was actually checked by limit gages and held to the specified tolerances, a variation of 0.002 or 0.003 inch was found to be an extremely small manufacturing tolerance. It is, therefore, one of the duties of the maker of the manufacturing design to specify the parts which are to be made interchangeable, those to be selectively assembled, and those to be fitted to each other. Careful attention to this detail saves much wasted effort in the shops subsequently.

Advantages of Unit Assembly Construction. Almost every mechanism can be subdivided into smaller units which are distinct in their purpose. For example, an automobile contains an engine, transmission, axle drive, carburetor, magneto, etc., which are assembled and tested as units and later assembled into the completed car. In like manner a typewriter is subdivided into the carriage, the escapement, the type-bar and the segment assembly, etc. The assembly is greatly facilitated if the design of the mechanism permits such unit assembly construction; and efforts should be made to obtain this result whenever practicable.

There are many other advantages of this unit assembly construction. Not only the various manufacturing departments of one factory but also entire plants are specializing more and more. The automobile has hastened this trend more than any other one thing. Where such unit assemblies are of equal value on several articles, separate plants spring up to produce them as a specialty. This gives the benefits of quantity production where otherwise they would not exist. Therefore, as a direct result of unit assembly construction, there are separate plants specializing in engines, rear axles, carburetors, magnetos, etc., for automobiles; ball and roller bearings for all types of machinery; and many other similar specialized products.

Standardization of Parts. Another practice which allows the benefits of quantity production to be obtained in the production of smaller numbers of complete mechanisms is the standardization of many of the individual components. For example, most manufacturing concerns have standardized their screws, nuts, studs, rivets, and others mall parts. The majority of machine tool builders also standardize their handwheels, micrometer thimbles, gears, tool-holders, work-arbors, etc. A good illustration of the economy of this practice is found in the experience of one plant which originally manufactured over one hundred and fifty special screws and studs for its particular product. Little effort was required to reduce this number to less than half, thus increasing the rate of production of these parts and also reducing the stock of spare parts. This practice

is extending to larger and more important components. Not only are similar parts produced by individual plants being standardized, but parts used in common by several manufacturers are also standardized and often manufactured as specialties by other concerns.

Designing for Assembling and Service. The design must permit the ready assembly of the product. Parts which require attention in service must be accessible. Attention to these details reduces assembling and service costs, and these must be considered to insure ultimate economy.

The service requirements are the most difficult to determine. Time alone brings the desired information. Experiments and endurance tests in the factory are insufficient to give it. After a mechanism is on the market, it receives use and abuse that the makers never dreamed of. Yet if the product fails under these unforeseen conditions, the manufacturing plant is blamed. Naturally the nature of the commodity determines what sort of service it must render. The service requirements of an automobile are distinct from those of a typewriter; those of a precision machine tool — which is supposedly used by skilled mechanics only — differ from those of a lawn-mower; etc.

The service requirements include the protection of the working parts from dirt and other foreign matter, the provision of proper lubricating facilities, and the protection of the operator from moving parts. The question of the best preservative finishes, such as japanning, plating, painting, etc., must also be answered to meet the service requirements, both of use and appearance. For these and many other similar problems a solution is sought that will result in the maximum amount of service at a minimum expense.

It should be clearly understood that the manufacturing design is not undertaken with the idea of wilfully altering the functional design, but is made to facilitate manufacture and to furnish as much as possible of that vast amount of detailed information previously brought to the productive work by the mechanic who carried out the inventor's ideas. The alterations made in the functional design by the manufacturing design should not

be looked on as any criticism of the original lay-out. Each has its distinct purpose to perform. Many large plants recognize clearly the difference between the two types of designing and maintain separate departments for each. The original research and inventive work is carried on independently of the factory operations. New or improved designs are turned over to the factory organization where they are redesigned to meet the manufacturing and service needs.

CHAPTER IV

PURPOSE OF MODELS

A MODEL mechanism, constructed personally by the inventor, or by the workmen under his immediate direction, was the original form of making and recording a new design. The introduction and development of mechanical drawings superseded many of the functions previously performed by the model. At the present time, therefore, the practice of developing models has been relegated to a comparatively insignificant place in most lines of manufacturing. They are still employed to a limited degree, however, by several manufacturers for a variety of purposes.

The primary purpose of any model at the present time is to prove — not to originate — a new or improved design that has been developed only on paper. It may be either to prove the possibility of the functional design or to check the manufacturing design. This may be done by a single mechanism in some cases, or several duplicate mechanisms may be required to prove its operation under various service conditions.

Manufacturing models may be used for one or more of the following purposes: First, to check the operation of the manufacturing design against the experimental model; second, to prove the manufacturing design in regard to the service requirements; third, to test the manufacturing tolerances which may be contemplated; and fourth, to create a physical standard of precision for future manufacturing.

Manufacturing Model to Test Functioning. A manufacturing model used to test the functioning of the manufacturing design is merely a sample mechanism constructed in the tool-room or machine shop to detect as many faults as possible in the design or to discover possible errors in the component drawings. It is essentially a precautionary measure. It is more economical to

detect and correct a fault on one sample than it is to salvage a large number of parts after production is started, with the additional expense of correcting the manufacturing equipment. After such a model has demonstrated the success of the manufacturing design and the correctness of the component drawings, its purpose has been achieved. Its future disposition is a matter of little moment.

Such a model is seldom necessary on simple mechanisms that are merely new combinations of old and proved mechanical movements, or on minor variations of proved designs, such as standard motors, dynamos, various types of engines, and many machine tools. The actions of such mechanisms under many conditions have been so well established that practically all of the necessary experimental work can be accomplished on paper. On many other mechanisms, however, such as typewriters, adding machines, small arms, watches, etc., the mechanical movements of which are delicate and intricate and not so positive, manufacturing models are a vital necessity. In general, such a model will be constructed when the insurance against the possible errors in the design is worth the expense entailed. For this reason it is often customary to build a pilot machine before putting through a lot of new or special machines.

If a new commodity is designed, particularly if it is to fill a new demand, it is advisable to determine its action in actual service before extensive productive operations are far advanced. The only sure method of obtaining this information is to have one or more mechanisms built and operated under the conditions with which they are expected to contend. The manufacturing model, which is built to test the manufacturing design, is often used for this purpose. As a matter of fact, the test for functioning should also include the tests for service requirements, inasmuch as this factor of functioning should include the measure of service which the mechanism must render throughout its normal life.

For example, a large plant in the Middle West goes thoroughly into this preliminary work on all new models. Three successive designs are developed and tested. First, the func-

tional or inventive design is made and tested. Second, the manufacturing design is carefully developed and tested by means of a manufacturing model. When this last design seems satisfactory, it is turned over to the tool designing department which goes over it a third time solely to simplify the tooling and mechanical productive operations. The changes made at this time, however, affect minor details only. From twenty-five to fifty mechanisms are built to this design and sent into the field for actual service. These last models must give satisfactory service for from one to two years before further preparations for manufacture are considered. It is of interest to note that the manufacturing equipment provided by this factory is complete; also that changes here in the process of manufacture or in the product under production are very rare.

Many of the so-called improvements in new commodities which result in frequent modifications of the product under manufacture are only steps taken to correct mistakes, omissions, and other faults due in large measure to neglect of the manufacturing design (both neglect to make and neglect to test it) because of haste to rush into actual production. This has been forcibly brought out by the conditions which developed in the manufacture of many devices during the war.

Models to Test Tolerances. It is desirable to know at the earliest possible moment whether or not the specified tolerances define the limits of parts that will function properly. The sooner this information is obtained, the sooner can efforts be concentrated on problems of production alone. Until this matter is settled within a reasonable degree of certainty, each problem in production is complicated by many considerations relating to the design and tolerances. This causes innumerable revisions on the component drawings with the attendant changes in tools, fixtures, and gages, resulting in delays in production and additional expense.

Some concerns try to solve this problem by carefully building several models which represent as closely as practicable the extreme conditions permitted by the component drawings. These model parts are assembled and reassembled, and tested

for operation after each assembly. Necessary alterations of the drawings are made before manufacturing operations are under way. This practice is, naturally, expensive, as each of these models costs much more to construct than any of the preceding ones. However, if insurance against future changes is worth the expense, the practice is well worth while.

One typewriter manufacturer makes a practice of building from six to ten sets of model parts before any new or revised machine is manufactured. When only one unit assembly is affected, model parts for that mechanism only are made. These parts are then sent to the assembling department for trial. Except on purely experimental models, the men who make the parts are not allowed to assemble them. No effort is made to do anything more than to duplicate the kind of work normally produced in the manufacturing departments. The parts are not cornered or burred unless that operation is required in manufacture. In other words, the attempt is made to determine how little effort will be required to manufacture the mechanism satisfactorily. The sizes of these parts usually cover the entire range between the specified limits, but no distinct effort is made to have them meet either limit exactly. Any combination of these parts must assemble and operate properly before changes or new models are adopted. This practice has saved the company several times from making unnecessary and improper changes.

Model for Standard of Precision. The component drawings give many dimensions. Strictly speaking, the expressed dimensions represent absolute sizes. Dimensions of elementary surfaces can be produced and reproduced within relatively small limits of error. Often, however, these dimensions define developed and complicated profiles, locations, and other composite surfaces which cannot be reproduced as readily. Yet they must be reproduced many times over in the course of manufacture to within relatively small limits of error.

A choice must be made between accuracy and precision at the outset. In the case of elementary surfaces, accuracy is usually the better choice; but for many composite surfaces,

precision will often give the quicker, more economical, and more practical results. On the other hand, it must be clearly understood that when precision is chosen, it becomes practically impossible for another plant, working in entire independence of the first, to produce a common interchangeable product. If more than one plant is engaged on the production, they must maintain close relations in almost every detail of the work. In order to maintain this precision within reasonably close limits, physical standards of some sort must be provided at the very beginning. By developing a model for this purpose, two results can be accomplished at the same time. Such a model will test the manufacturing design for functioning, and will also provide the desired physical standards.

This model must be made with the greatest care and should represent the "danger zone" — that is, in most cases, the maximum metal or minimum clearance conditions. It is evident that these sizes are the most important. They control the interchangeability. No cuts, other than slight cornering and similar burring operations, should be made with a hand tool, such as a file. Whenever the contour of the surface in question is important, templets should be made to check the special tools used. These templets are an integral part of the model. All important locations of holes should be established from master plates. Templets, master plates, etc., as well as the model parts, are invaluable when the equipment is built; properly utilized, they will insure a high degree of uniformity at relatively small expense. Such a model must be used with the greatest care and becomes the court of last appeal in many of the perplexing questions which inevitably arise in the manufacturing departments of a plant engaged in producing an interchangeable product in large quantities.

This practice in regard to models is extensively followed in the manufacture of small arms. As stated before, it has a certain disadvantage when more than one factory is involved. As it is impossible to duplicate the model exactly, one of two courses is open. Either one model is standard for all plants — which entails much lost time in referring many detailed ques-

tions back to the central plant — or additional models may be made, which results in different basic standards at the various plants. If the second course is followed, and all parts of all models are mutually interchangeable, the product of the various factories will be interchangeable. However, this results in reducing the amount of the absolute tolerances available for manufacturing variations, as the variations in the different models consume a certain amount. In cases where the functional conditions are exacting, this method is often found impracticable. On the other hand, if the design of the mechanism is such that the absolute tolerances are liberal, the second method gives an economical solution.

All the foregoing model work, regardless of its purpose, is essentially a preliminary measure in the manufacture of a new or revised product. Properly conducted, it will stabilize the manufacturing design at a minimum expense. It takes considerable time, however, and that is one reason why models are not more extensively employed. For any commodity that is already under manufacture and the design of which is already standardized, models are of doubtful value.

CHAPTER V

PRINCIPLES IN MAKING COMPONENT DRAWINGS

THE art of expressing mechanical information by means of drawings is still in the process of evolution. Many details have become conventionalized, yet these comprise little more than the alphabet of the language of drawings and relate principally to conventional meanings of the lines, figures, and relative locations of the several projections which go to complete the drawings. Such, for example, are the full lines which represent the visible outlines of the part; the dotted lines which represent the hidden outlines; the light dot-and-dash lines which indicate center lines; the light dimension lines — and all the other conventional lines and characters which are employed. The third-angle projection is also fairly well established in mechanical drawing. This branch of drawing is fully covered in text-books, so no further mention of it will be made here. The subject of dimensioning, however, is so incompletely covered that this chapter will be devoted to a detailed discussion of this subject. The addition of tolerances on component drawings has created new problems which have not, as yet, been fully solved, and which, therefore, require considerable and thoughtful study.

The matter of dimensioning, as given in books and taught in various schools, receives only minor attention. Little more than the a b c of the subject is taught. In actual practice — particularly where tolerances are involved — so many different conditions are to be met, so many different shades of meaning must be clearly expressed, and so many different types of workmen must be informed by these drawings that this alphabet must be fully understood and carefully used to enable it to serve its purpose. It is necessary, in order to consider intelligently this subject of dimensioning with tolerances, to discard all school training in the application of dimension lines, etc.

The main purpose of a mechanical drawing is to express or record information. This information is of many kinds and is used for many purposes. The drawing, to be correct, must clearly and consistently express the particular information required to serve its specific purpose. For example, a type of drawing that may be correct for the use of a toolmaker in building a jig may be incorrect for the use of a machine operator in the manufacturing department engaged in quantity production. Inasmuch as the drawings are the written or pictured expression of the design, they may be roughly classified into functional drawings and manufacturing or component drawings.

Functional Drawings. The functional drawing, like the functional design, primarily expresses the functional conditions to be maintained. The detailed information relating to many of the manufacturing problems that are involved which does not appear on these drawings is supplied by the mechanic who uses them. Thus, in those cases where only a few special mechanisms, or jigs, fixtures, tools, etc., are to be made in a general machine shop or tool-room, where the type of workman is such that this detailed information is unnecessary, functional drawings only are required. Such drawings need not express tolerances, clearances, and other minor details so essential on the manufacturing drawings. For example, a notation such as "drive fit" or "sliding fit" is sufficient to indicate and obtain the desired results. Yet, even here, if the drawings are to serve their purpose efficiently, the information given must be so expressed that it may be used directly. In order to attain this end, every line drawn and every dimension expressed must be made with a full understanding of the final results required and of the means to be employed to obtain them.

Manufacturing Drawings. The manufacturing drawings, to be complete, must express all suitable information that is available. For the purposes of the present discussion, we will confine ourselves to component drawings of an interchangeable product. As stated in a preceding chapter, the proper dimensioning of component draiwngs with tolerances is a mathematical problem. Five laws are given, which, if carefully

observed, will simplify many of the equipment and production problems.

Laws of Dimensioning. 1. In interchangeable manufacturing there is only one dimension (or group of dimensions) in the same straight line which can be controlled within fixed tolerances. This is the distance between the cutting surface of the tool and the locating or registering surface of the part being machined. Therefore, it is incorrect to locate any point or surface with tolerances from more than one point in the same straight line.

2. Dimensions should be given between those points which it is essential to hold in a specific relation to each other. The majority of dimensions, however, are relatively unimportant in this respect. It is good practice to establish common location points in each plane and to give, as far as possible, all such dimensions from these points.

3. The basic dimensions given on component drawings for interchangeable parts should be, except for force fits and other unusual conditions, the maximum metal sizes. The direct comparison of the basic sizes should check the danger zone, which is the minimum clearance condition in the majority of cases. It is evident that these sizes are the most important ones, as they control the interchangeability, and they should be the first determined. Once established, they should remain fixed if the mechanism functions properly and the design is unchanged. The direction of the tolerances, then, would be such as to recede from the danger zone. In the majority of cases, this means that the direction of the tolerances is such as will increase the clearance. For force fits, such as taper keys, etc., the basic dimensions determine the minimum interference, while the tolerances limit the maximum interference.

4. Dimensions must not be duplicated between the same points. The duplication of dimensions causes much needless trouble, due to changes being made in one place and not in the others. It causes less trouble to search a drawing to find a dimension than it does to have them duplicated and more readily found but inconsistent.

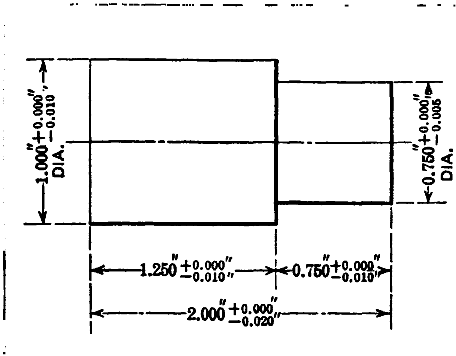


Fig. 1. Common but Incorrect Method of Dimensioning

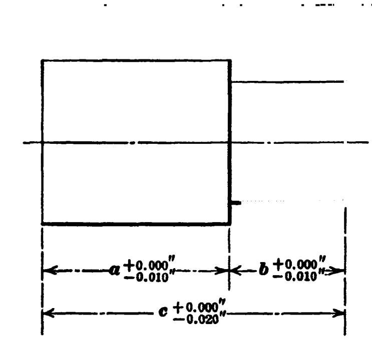


Fig. 2. One Interpretation of Dimensioning in Fig. 1

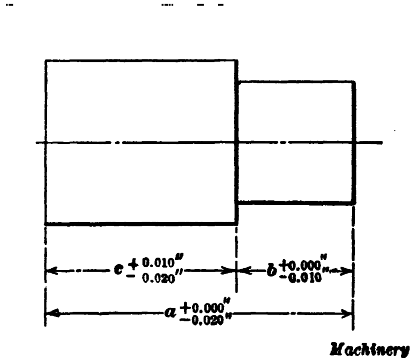


Fig. 3. Another Interpretation of Dimensioning in Fig. 1

5. As far as possible, the dimensions on companion parts should be given from the same relative locations. Such a procedure assists in detecting interferences and other improper conditions.

When attempting to work in accordance with general laws or principles, one other elementary rule should always be kept in mind. Special cases require special consideration. This may be another method of saying that the exception proves the rule. The following detailed examples are given to illustrate the application of these five laws and to indicate results of their violation.

Violation of First Two Laws. For the first example, we will take the stud shown in Fig. 1. This shows a very common method of dimensioning such a part, but one that is extremely bad practice. It violates the first and second laws given above. As the dimensions given for the diameters are correct, they are eliminated from the discussion. The dimensions given for the various lengths are wrong:

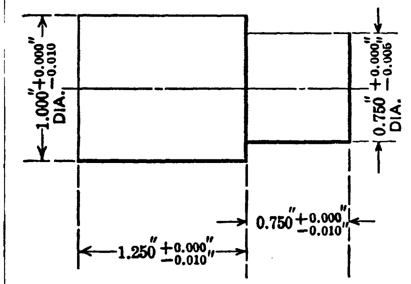


Fig. 4. Correct Dimensioning if Length of Body and Length of Stem are Most Important

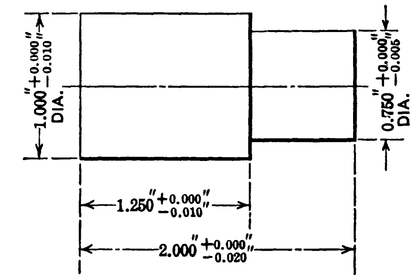


Fig. 5. Correct Dimensioning if Length of Body and Over-all Length are Most Important

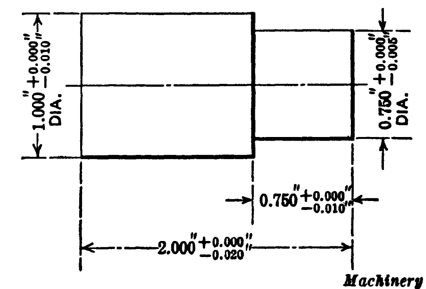


Fig. 6. Correct Dimensioning if Over-all Length and Length of Stem are Most Important

first, because they give no indication as to the essential lengths; second, because of several possible sequences of operations, some of which would not maintain the specified conditions. Composite surface conditions are created, whereas they should be kept elementary.

Fig. 2 shows one possible sequence of operations indicated alphabetically. If we first finish the dimension *a* and then finish *b*, the dimension *c* will be within the specified limits. In this case, however, the dimension *c* is superfluous. Fig. 3 gives another possible sequence of operations. If we first establish *a*, and then *b*, the dimension *c* may vary 0.030 instead of 0.010 inch as is specified in Fig. 1. Fig. 7 gives a third possible sequence of operations. If we first finish the over-all length *a*, and then the length of the body *b*, the stem *c* may vary 0.030 inch instead of 0.010 inch as specified in Fig. 1.

If three different plants were manufacturing this part, each one using a different sequence of opera-

tions, it is evident from the foregoing that a different product would be received from each plant. The example given is the simplest one possible. As the parts become more complex, and the number of dimensions increase, the number of different combinations possible and the extent of the variations in size that will develop also increase.

Fig. 4 shows the correct way to dimension this part if the length of the body and the length of the stem are the essential dimensions. Fig. 5 is the correct way if the length of the body and the length over all are the most important. Fig. 6 is correct if the length of the stem and the length over all are the most important.

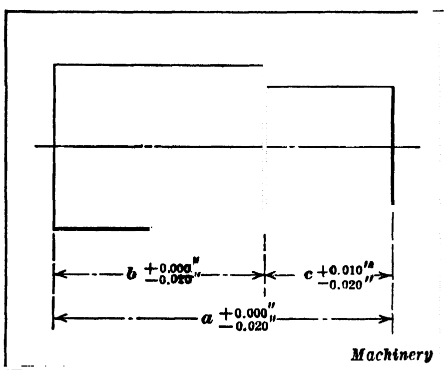


Fig. 7. A Third Interpretation of Dimensioning in Fig. 1

If the part is dimensioned in accordance with either Fig. 4, Fig. 5, or Fig. 6, the product from any number of factories should be alike. There is now no excuse for them to misinterpret the meaning of the drawing. The point may be raised that the manufacturer should study the drawing to determine what his sequence of operations should be in order to maintain all dimensions and tolerances given. On such a simple part as was given for the first example, this would not be difficult. On a more complicated piece, however, it would be almost impossible. Such conditions occur when the draftsman makes little or no effort to reduce as many surfaces as possible to elementary ones. Furthermore, when the manufacturer or workman sees such dimensions on a component drawing, he is justified in assuming that the designer or draftsman who made them had little or no idea as to the essential conditions to be maintained. In such cases, the sequence of operations and the register points for machining will be established to facilitate production, or to suit the ideas of individuals as to the most essential conditions.

Often, this will result in some of the operations on a component being arranged to suit one idea, while the remainder are completed in accordance with an almost diametrically opposed conception. It cannot be too strongly impressed upon the draftsman that when a drawing leaves his hands it must not be open to more than one interpretation. This, in turn, demands that a uniform method of interpretation be adopted and published by each plant for the guidance of all concerned. It is self-evident that a universal method of interpretation of drawings with tolerances would be of great benefit to all manufacturing plants.

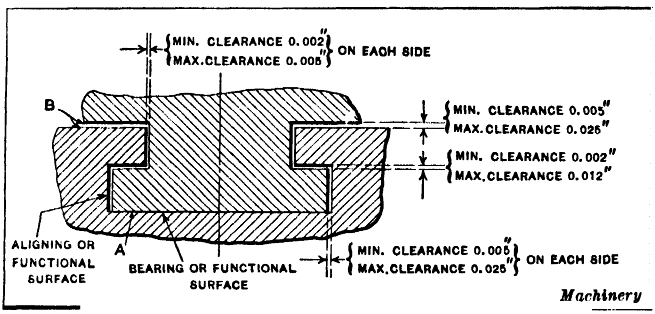


Fig. 8. Sketch showing Functional Requirements of Slide

This is a field where the various engineering societies, working in close coöperation, could render valuable service.

Violation of the Second Law. Let us take as the second example the slide shown in the sub-assembly, Fig. 8. This sketch gives the functional conditions which must be maintained. It is well to note that it is a very desirable practice to add to a set of component drawings a series of sub-assemblies of this kind. These would show graphically the functional requirements of the most important operating members of the mechanism, when the detail drawings are insufficient, in themselves, to express them clearly. Such a practice will prove of great assistance in limiting the interpretation of the component drawings.

Fig. 9 illustrates a common method of dimensioning such details. This is wrong, as it violates the second law previously stated. These parts are dimensioned in Fig. 10 in accordance

with the foregoing laws. It will be noted that all dimensions for height are given from the bearing surface *A*, which is the most important in this case. If the slide should be designed to bear at *B* instead of at *A*, surface *B* would become the most important, and the various dimensions of height would be given from there instead of from *A*. The same functional conditions (see Fig. 8) are maintained in Figs. 9 and 10. Attention is

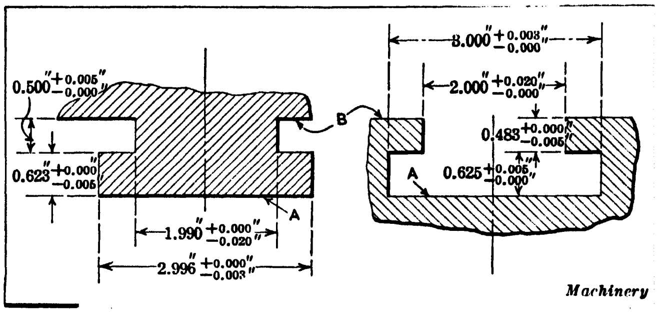


Fig. 9. Incorrect Dimensioning of Slide shown in Fig. 8

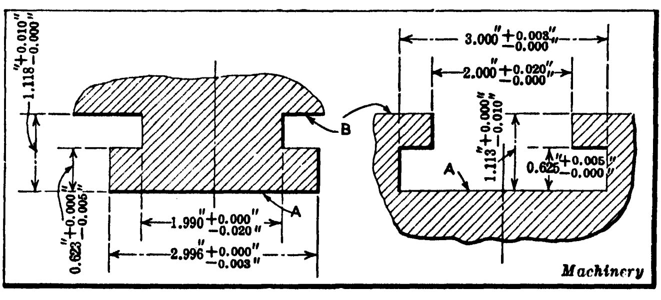


Fig. 10. Proper Dimensioning of Slide shown in Fig. 8

called to the fact that in Fig. 10 it is possible to allow a tolerance of 0.010 inch on the dimension to the top surface *B*, whereas in Fig. 9 only 0.005 inch can be allowed as a manufacturing tolerance when making this cut.

Increasing Possibility of Draftsman's Errors. Thus, the improper and careless dimensioning of component drawings results directly in reducing the manufacturing tolerances, in addition to creating uncertainty by not indicating the essential surfaces. Furthermore, the possibility of draftsman's errors is greatly

increased by dimensioning as shown in Fig. 9 because the draftsman, in this case, must make several additions and subtractions of basic figures and tolerances in order to check the maximum and minimum clearances. In Fig. 10, on the other hand, the direct comparison of the basic dimensions checks the minimum clearance. The maximum clearance is readily checked by adding the sum of the tolerances to this minimum clearance. In general, the direct comparison of the basic dimensions should establish the minimum clearances between elementary surfaces on companion parts.

No mention has been made of the dimensions of width in the previous example. Strictly speaking, dimensions so given

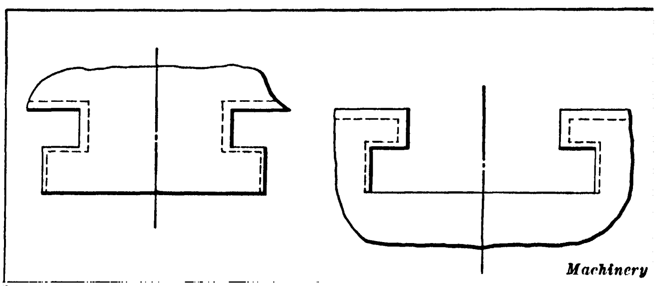


Fig. 11. Graphical Illustration of Application of Tolerance

are central with the center line. Half of the tolerances for width may be utilized on either side of the center line. This does not mean that the surfaces must be absolutely central; one side can be made to the maximum dimension and the other side to the minimum. In general, the tolerances should be understood to establish a parallel zone of acceptable work, all parts falling within this zone being acceptable. Fig. 11 illustrates how the dimensions and tolerances in Fig. 10 establish such a zone. The full lines show the basic or maximum metal conditions, while the dotted lines show the minimum metal conditions.

Inspection Gage Requirements. In the previous example, each surface has been considered as an independent elementary surface, and the meaning of the drawing interpreted accordingly. But there is also a certain condition of alignment which these

various surfaces must maintain in relation to each other. When considering this phase of the subject, the surfaces become composite. Whenever composite surfaces are involved, the functional requirements of these surfaces must be taken into consideration. The only satisfactory method of solving such problems is in terms of the inspection gage requirements. If the succeeding solutions are accepted, the accompanying interpretations, expressed in terms of functional gages, must also be accepted.

To a certain extent, the amount of tolerance required to machine a given surface depends on the methods employed to check the results obtained. For example, the maximum thickness of the tongue of the slide shown in Fig. 10 is 0.623 inch. If this thickness is checked with an ordinary snap gage, practically the entire tolerance is available for variations in thickness. If, however, the width of this snap gage were equal to or greater than the length of the tongue, any deviations in the surfaces checked from true parallel planes would tend to prevent the part from entering the gage. In this case, part of the tolerance would be consumed by the errors in alignment of the two surfaces, leaving the remainder for variations in the distance between them.

One of the principal reasons for providing clearances in the design is to discount this condition of misalignment. In developing functional gages to check these conditions, therefore, we are justified in utilizing a fair percentage of the minimum clearance. In order to insure strict interchangeability, the functional gage for the male component should never be larger than the functional gage for its companion female component. In general, if the functional gages never invade this minimum clearance more than fifty per cent, we shall remain on the safe side. Conditions sometimes arise, of course, where it is desirable to utilize a greater percentage on one component and a correspondingly lesser percentage on the other. For the purposes of this discussion, however, we shall assume that the conditions are such that a maximum of fifty per cent for each component represents a fair distribution.

The dimensions for functional gages to check the parts shown in Fig. 10 are given in Fig. 12. The various dimensions of the parts should first be checked as elementary surfaces with limit gages representing the specified limits. This functional gage would then be employed to test the relative alignment of these surfaces necessary to insure interchangeability.

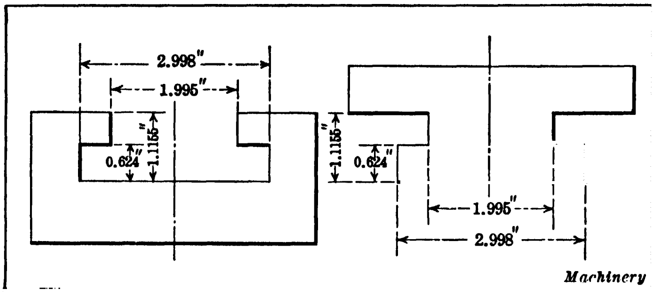


Fig. 12. Dimensions for Functional Gages for Part shown in Fig. 10

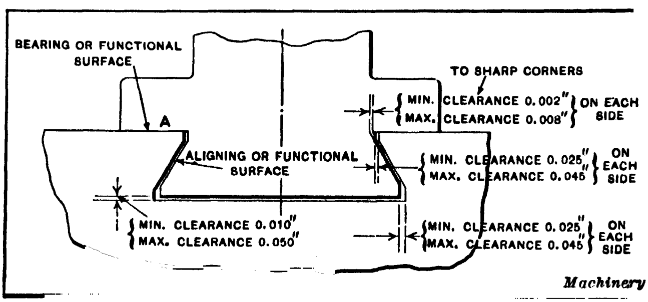


Fig. 13. Sketch showing Functional Requirements of Dovetail Slide

Dimensioning Composite Surfaces. Thus far we have been considering parts whose surfaces are susceptible of individual checking as elementary surfaces. We must also consider parts whose surfaces cannot be resolved into elementary ones and checked as such. Take, for example, a dovetail slide, such as shown in Fig. 13, which introduces an angular surface. Such angular surfaces are almost always composite ones. Great care must be exercised in such cases to avoid compound tolerances.

A compound tolerance exists when the application of a tolerance on one dimension develops a variation in another dimension which also has a tolerance specified. Such a condition immediately raises the question as to whether the resultant variation of both tolerances is permissible or whether the tolerances specified are final and complete for their respective dimensions. In either event, confusion and misunderstanding will result. Here, as with the introduction of more than one dimension in the same straight line (see first law of dimensioning) to locate a given surface, the final results will depend on the sequence of operations adopted, with all the attendant differences.

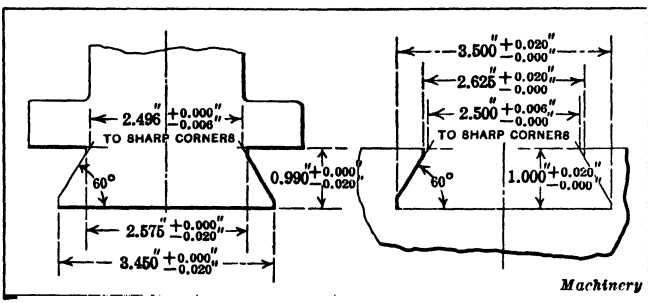


Fig. 14. Correct Dimensioning of Dovetail Slide shown in Fig. 13

As stated in the chapter "Principles of Interchangeable Manufacturing," in making component drawings, the effort should be made to so give the dimensions and necessary tolerances that it would be possible to lay out one — and only one — representation of the maximum metal condition and one — and only one — minimum metal condition. If such lay-outs were superimposed, the difference between them would represent the permissible variation on every surface. If a few such lay-outs are made, it will soon be evident that there are always a number of dimensions that should be given without tolerances.

A compound tolerance is an error — often a serious one. It can and should always be eliminated. Fig. 14 illustrates a method of dimensioning the dovetail slide shown in Fig. 13 which avoids compound tolerances. The dimensions that control the position of the angular flanks are given to the sharp

corners at the top of the dovetail. The tolerances on these dimensions limit the permissible variation of these angular flanks. The angle is given as a flat dimension. As is evident from the functional drawing, Fig. 13, the bearing surface *A* and these angular flanks are the essential functional surfaces of this dovetail. All other surfaces are clearance surfaces, as should be apparent from the extent of the tolerances, Fig. 14, even though the functional drawing were not available. Fig. 15 shows graphically the applications of the tolerances given in Fig. 14. The full lines represent the maximum metal con-

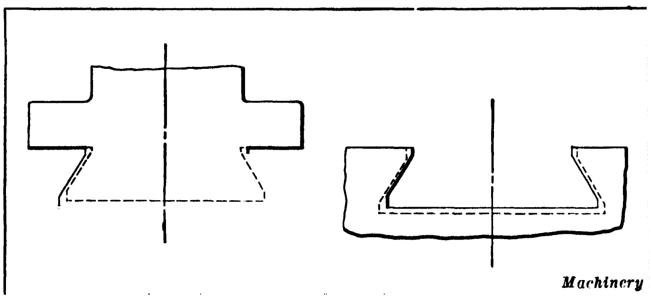


Fig. 15. Graphical Illustration of Application of Tolerances

ditions, while the dotted lines indicate the minimum metal conditions.

Compound Tolerances. The dimensioning of tapered plugs and holes introduces a somewhat similar problem which will result in a condition of compound tolerances if great care is not exercised. Fig. 16 shows such a tapered hole as it is usually dimensioned. This method of dimensioning is wrong, as it creates a condition of compound tolerances. With these dimensions, it is impossible to determine what final result is required, since there are so many possible combinations. It is evident that as the diameter of either the large or the small hole varies, the taper will change. This makes an uncertainty about the reamers, as these tools have a fixed taper. If we assume that the taper is constant, questions will be raised as to which combination of limits to employ to establish the taper. If we further assume that the basic dimensions are to be used

for this purpose, the next question will be whether this taper, considered as a constant, is required to remain in the position indicated by the dimension 1.000 inch $^{+0.010}_{-0.000}$ under all conditions, or whether it can also vary in addition by the amount resulting from the variations in diameters. Also a tolerance is given on the length of the taper. This is entirely meaningless. It cannot be measured readily even with an elaborate laboratory equipment and there is no use for this tolerance in the course of manufacture. With a fixed taper, the variation in this length is controlled absolutely by the relative size of the holes. All in all, as the drawing stands, it is a puzzle without any solution.

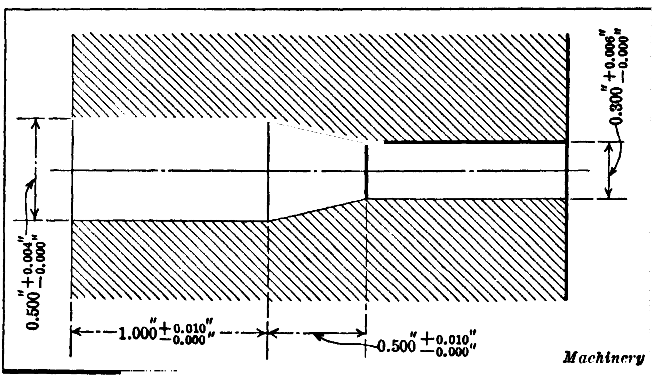


Fig. 16. Incorrect Method of dimensioning Tapered Hole

We will assume that the intent of Fig. 16 is to indicate a constant taper with a tolerance of +0.010 inch in regard to its position. Fig. 17 shows the correct method of dimensioning such a surface to maintain such a condition. An arbitrary point is taken on the taper and a fixed dimension given for its diameter at that point. The location of this fixed diameter is dimensioned with the tolerance. Three methods of dimensioning this taper are shown. Either of the first two, *A* or *B*, is preferable to the third, *C*, because any reference figures desired can be readily computed from them without recourse to trigonometry or any tables or handbooks.

Fig. 17 gives the manufacturer definite information which he can use and which he can use in only one way. The tolerances

given on each dimension apply only to the specific surface in question. No tolerance can be given on the diameter of the taper nor on the angle without introducing compound tolerances again, with resultant confusion. The permissible variations on this tapered surface are fully established by

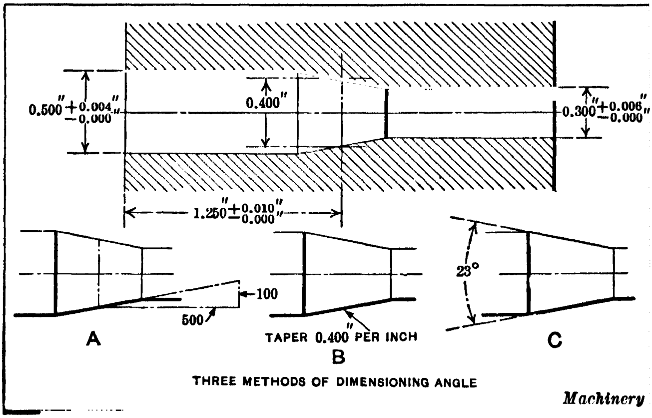


Fig. 17. Correct Method of dimensioning Tapered Hole

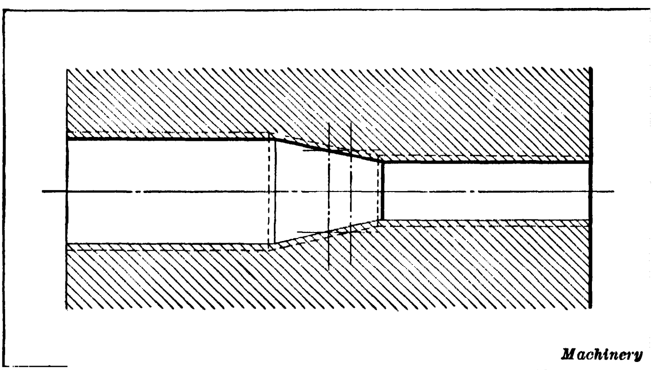


Fig. 18. Graphical Illustration of Application of Tolerance

the tolerance given on its location. Fig. 18 shows graphically the maximum and minimum metal conditions established by the dimensions and tolerances given in Fig. 17. It will be noted that a parallel zone for the permissible variations has been established on every surface. When this has been accomplished, no further tolerances should be given.

The method of dimensioning a taper shown in Fig. 17 usually meets with more or less opposition from the shop men. The objection is raised that more dimensions are necessary in order to make up the proper reamers, etc. Although the needed dimensions can be readily computed, it is desirable to reduce the amount of such computations in the shop as much as possible. This objection can be eliminated in several ways. First, if a drawing is made for the reamers, all the additional checking dimensions can appear on these drawings. Second, if operation drawings are provided, these dimensions would appear

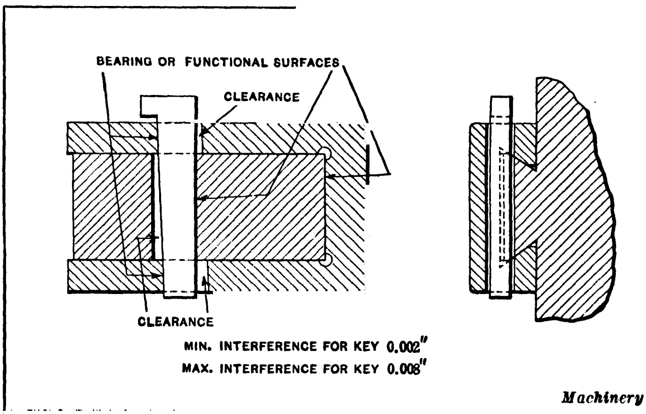


Fig. 19. Functional Requirements for a Taper Key

there. Third, if neither of the two foregoing practices is adopted, the required dimensions may appear on the component drawing in parentheses, and may be marked "Basic" or "Reference." It should be clearly understood, however, that such dimensions are supplementary and apply only in connection with the other basic dimensions given. No tolerances should under any circumstances be given on such reference figures. As far as possible they should be eliminated from the drawing.

Dimensioning Force Fits. The dimensioning of a taper key and its seat offers a very instructive example. In this case, we have a drive fit so that instead of clearances we must concern ourselves with the establishment of the proper interferences. Fig. 19 illustrates such a key and its seat. The functional con-

ditions to be maintained demand that we have always an interference of at least 0.002 inch and never have a greater interference than 0.008 inch. The illustration shows clearance at those points at which no bearing is required. Often, however, we find drawings for such functional conditions specifying fits on all surfaces. Such conditions add nothing to the strength or effectiveness of the construction but entail unnecessary refinement in the manufacture of the detailed parts with a correspondingly increased

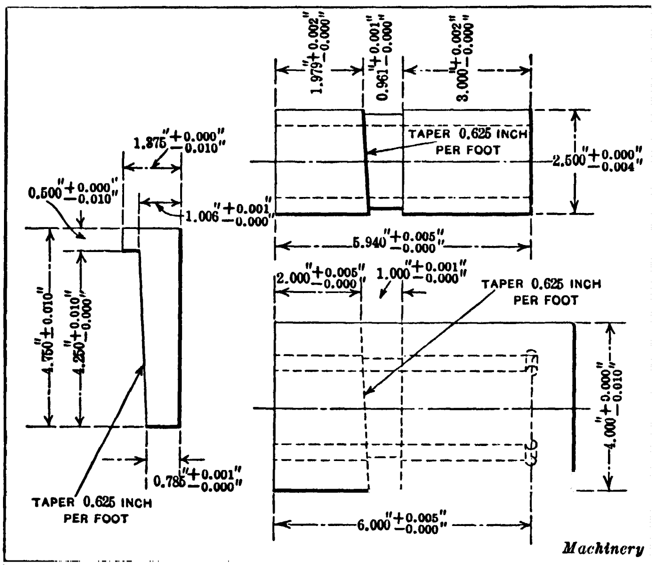


Fig. 20. Incorrect Dimensioning and Design of Details shown in Fig. 19

cost. Fig. 20 illustrates the details of such a condition dimensioned in a very common manner. This method of dimensioning is wrong. The key in this sketch violates the first, second, third, and fifth laws of dimensioning; the slide violates the second, third and fifth laws; while the dimensioning on the seat violates the first, second, third, and fifth laws. With the dimensions given as they are, it is impossible to specify tolerances that will insure the required functional conditions unless we reduce each tolerance to a fraction of a thousandth. The dimensions and the tolerances as they stand permit, in some cases, the key

to be tight in the slide and loose in the seat of the slide. In other cases, the reverse is true. Parts made to the basic dimensions will have a fit on all surfaces.

Fig. 21 shows these parts dimensioned in accordance with the laws of dimensioning. It will be noted that with parts made to the basic dimensions, the key will be driven home to its head, with an interference on the bearing surfaces specified of 0.002 inch. The direction of the tolerances on every dimen-

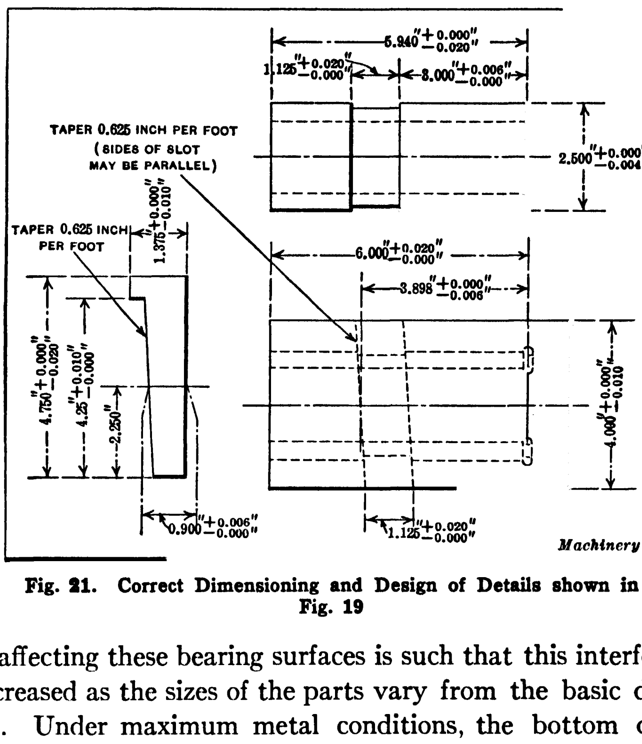


Fig. 21. Correct Dimensioning and Design of Details shown in Fig. 19

sion affecting these bearing surfaces is such that this interference is increased as the sizes of the parts vary from the basic dimensions. Under maximum metal conditions, the bottom of the key will be flush with the bottom of the slide with an interference of 0.008 inch on the functional surfaces. It should be noted that by giving the dimensions in this manner, the required conditions are always maintained, while the manufacturing tolerances are greatly increased. Both slots are made with parallel sides to facilitate machining. Fig. 21 offers a good example of the application of the fifth law of dimen-

sioning. This illustration should be carefully studied and compared with Fig. 20. Note, in particular, the ease of checking the functional conditions in Fig. 21 as contrasted with the difficulty and confusion which arises if we attempt to determine the possible combinations permitted in Fig. 20. Note also how the relative extent of the tolerances specified in Fig. 21 calls attention to the essential functional surfaces. These same relative conditions exist between any drawings that are dimensioned without careful study as compared with those which are rationally and logically dimensioned. No attempt has been made

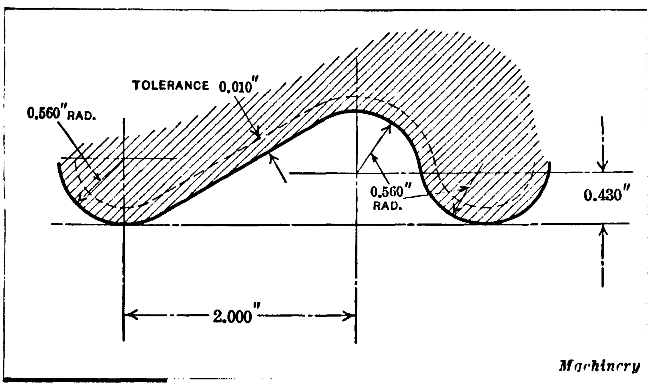


Fig. 22. Sketch showing Satisfactory Method of specifying Tolerance on Contours

in this example to express any dimensions other than those which affect the taper key and its seat. The example given in Fig. 14 shows the proper dimensioning of the dovetail slide.

Dimensioning of Profile Surfaces. The dimensioning of contours with tolerances introduces still another problem. To give tolerances on the various dimensions which establish the basic contour inevitably introduces compound tolerances. On the other hand, it is often impossible to resolve such composite surfaces into elementary ones for the purposes of dimensioning and checking, because their dimensions and relative locations are inseparable. Fig. 22 illustrates one satisfactory solution of this problem. The basic dimensions of the profile are given without tolerances. A dotted line is drawn parallel to the basic

contour which indicates the direction of the tolerance. A dimension is given between the full (or basic) outline and this dotted line which specifies the extent of the tolerances. This method of dimensioning gives definite information which can be used directly in the manufacturing departments.

Dimensioning of Holes. The dimensioning of the location of holes with tolerances is a most difficult problem. These dimensions are usually given to the centers of the holes and define neither male nor female surfaces. They must be used in conjunction with the diameters of the holes, thus establishing a composite surface condition. The introduction of tolerances on

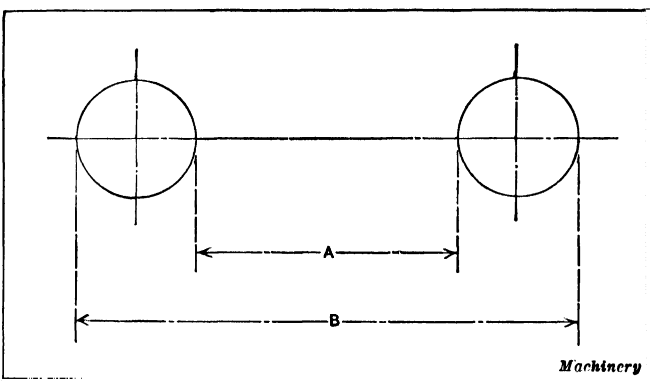


Fig. 23. Diagram illustrating Conditions met with in measuring Holes

these dimensions of location immediately will produce compound tolerances.

We might dimension them as shown in Fig. 23 by giving one dimension to the inside edges of the holes (which is a male dimension), another to the outside edges of the holes (a female dimension), and eliminate the dimension for diameter. This would give us a better opportunity of applying the five laws of dimensioning in a similar manner to that employed for elementary surfaces. However, this would prove unsatisfactory in practice because it does not give directly the information which is of most value in the shop — namely, the diameters of the holes and the center distances.

No rules can safely be given for dimensioning the location of holes in which the permissible variations are distinctly expressed, unless the required functional conditions are duly considered. The following examples give possible solutions of a few of these problems. If these solutions are accepted, the corresponding interpretations, expressed in terms of inspection gage requirements, must also be accepted. For the first example, we will take the base for a bracket and its pad on a frame illustrated in Fig. 24. We will assume that the position of this bracket on the frame is important and must be held as closely as manufacturing conditions will permit. We will assume also that the

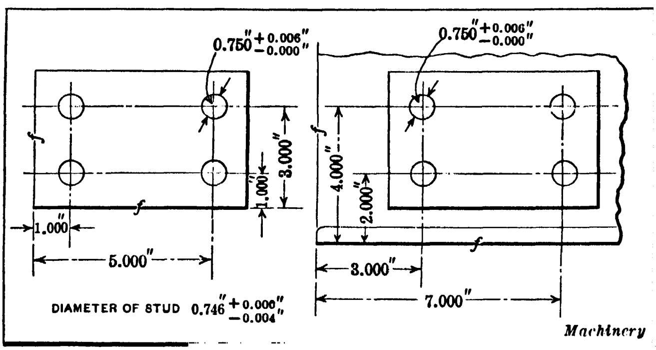


Fig. 24. Methods of dimensioning the Location of Holes

jigs from which these holes are drilled locate the parts on the finished surfaces from which the dimensions are given.

Causes of Variation in Manufacture. Variations of locations in manufacture develop from three main causes: First, from a fixed error in the jig; second, from a difference in size between the drill and its bushing in the jig; and third, from improper location of the parts in the jigs. Variations occurring because of the first cause will affect the locations of the holes both in relation to each other and to their locating surfaces. Variations because of the second cause will have similar effects to those developing from the first cause. Variations because of the third cause will affect only the location of all holes as a unit from the locating surfaces. Thus, with these problems, there are always composite variations with which to contend. The

surfaces involved are always composite, and a condition of compound tolerances is always present.

If precision, rather than absolute accuracy, is the main consideration, and if these locations in the two jigs check with each other, the variations due to the first cause may be disregarded, provided that the gages which check these locations are made to agree with the jigs.

The variations due to the second cause may be reduced to comparatively small amounts by closely maintaining the relative diameters of the drills and their bushings. This naturally involves a somewhat increased maintenance cost of the equipment. The extent of the variations due to the third cause

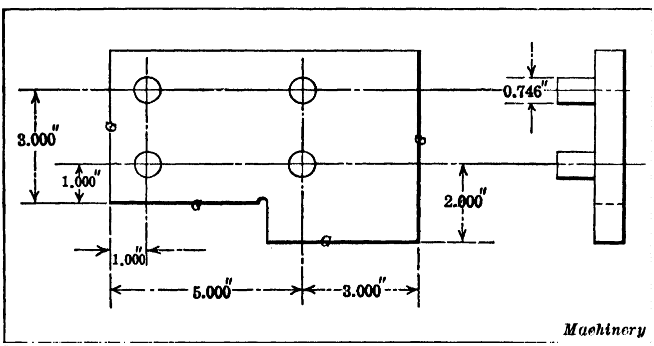


Fig. 25. Functional Gage for Part shown in Fig. 24

depends upon the design of the jigs and the care exercised by the operator. In general, the third cause is responsible for the largest amount of variation.

The locations in Fig. 24 are given without tolerances, yet the drawing should not be interpreted to mean that no variations are permissible. The minimum clearance between the studs and the holes is 0.004 inch. This clearance is provided to allow for the variations in their locations. Therefore, this clearance should be considered in testing the locations of these holes.

Gages for Checking Location of Holes. The inspection gage for testing these locations would be a functional gage which invades this minimum clearance. There are two conditions to be considered here which affect the amount of the minimum

clearance that may be used on the gage. If the studs used are loose, individual pieces which pass through both parts and are bolted or riveted at assembly, the functional gage may utilize the entire minimum clearance. On the other hand, if the studs are first driven or riveted into one member, these functional gages could invade the minimum clearance not over fifty per cent. In either case, it is possible to make a single gage which will check both parts.

We will first consider the functional gage to check the first of the above conditions. This gage would consist of a plate with four pins, as shown in Fig. 25. It checks both the locations of the four holes relative to each other and the location of

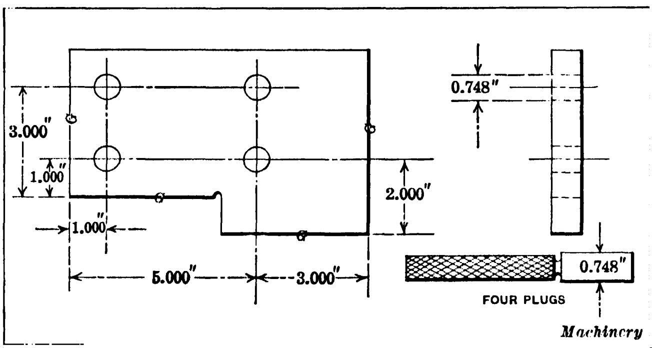


Fig. 26. Another Type of Functional Gage for Part shown in Fig. 24

the group from the edges of the part. The locations of the pins are identical with the corresponding basic dimensions given on the component drawings. The diameter of the pins is 0.746 inch (basic diameter of hole minus minimum clearance). The gage must always enter all four holes on the part. When the gage is held against the upper edge of the holes, the lower edge of the gage must not project below the lower edge of the component. When held against the lower edge of the holes, the lower edge of the gage must not be above the lower edge of the part. This checks the vertical position of the holes. The horizontal locations are checked in a similar manner. The diameters of the holes are checked as elementary surfaces with limit plug gages made to the specified limits.

Thus, although both the drawings and the gages are made to flat dimensions, a tolerance on all positions of the holes has been established. If their relative locations were perfect, under maximum metal conditions of the various holes, a variation of 0.002 inch either way would be permitted on their location from the edges of the parts. If the various holes were made to the maximum limits, this variation could be 0.005 inch either way. On the other hand, if the position of these holes as a unit were perfect in regard to the edges of the components, a variation of 0.004 inch would be permitted on their relative locations under maximum metal conditions, with a correspondingly increasing

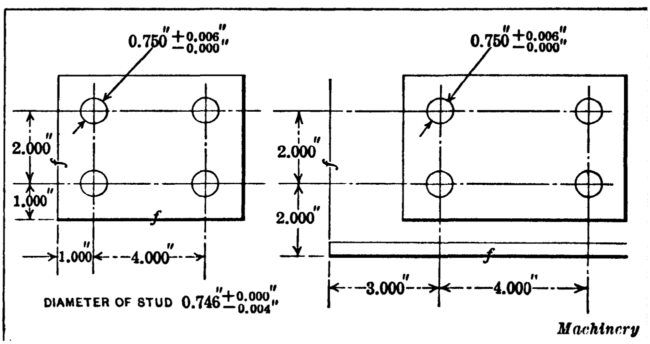


Fig. 27. Method of dimensioning Location of Holes without Tolerances

tolerance as the parts approach minimum metal conditions. This would amount to 0.010 inch at the extreme minimum metal condition. Inasmuch as variations will develop in both types of locations, all that is not consumed by one is available for the other.

We will now consider the functional gage to check the condition where the studs are rigidly fastened to one of the parts. A gage for this purpose would be similar to the one shown in Fig. 25 except that it would contain four holes instead of four pins. Such a gage is shown in Fig. 26. Four plugs would be used with this gage for testing the locations of the holes in one piece, while the holes in the gage would go over the studs fastened to the companion part. The diameter of the holes in this

gage and also of the plugs is 0.748 inch (basic diameter of hole minus one-half minimum clearance or basic diameter of stud plus one-half minimum clearance). This gage would be used in exactly the same manner as the first. The permissible variations under maximum metal conditions of the holes and studs would be but one-half that permitted in the first case. As these holes and studs approach minimum metal conditions, the permissible variations in location would increase in the same manner and extent as in the first case.

In Fig. 24, the locating dimensions are given from common locating surfaces in each direction. They could be given as

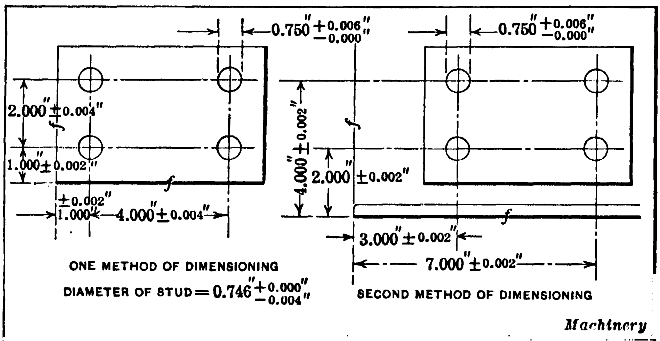


Fig. 28. Two Methods of Dimensioning with Tolerance which maintain Identical Conditions

shown in Fig. 27. As long as no tolerances are expressed, the method most convenient for the shop is best.

Expressed Tolerances on Location of Holes. If expressed tolerances for locations of holes are insisted upon, it is impossible to avoid compound tolerances. Then an arbitrary method of interpretations must be promulgated to prevent continual argument and misunderstanding. Fig. 28 illustrates two methods of indicating such tolerances. We assume that the functional conditions are identical with those previously discussed in the first case of Fig. 24. This is one example where the mean size is the proper basic dimension, and tolerances apply equally plus and minus.

In order to establish the sizes of inspection gages we must consider the tolerances, instead of minimum clearances. Re-

ferring to Fig. 23, an inspection gage to check the relative locations of the holes must be made to the maximum dimension *A* and the minimum dimension *B*. In the horizontal direction, the maximum limit of *A* is equal to the maximum center distance (4.004 inches) minus the minimum diameter of the hole (0.750 inch) which amounts to 3.254 inches. The minimum limit of *B* in the same direction is equal to the minimum center distance (3.996 inches) plus the minimum diameter of the hole (0.750 inch) which is equal to 4.746 inches. The difference between *A* maximum and *B* minimum gives double the diameter of the pins on the inspection gage, which amounts to 1.492 inches. The diameter of these pins is therefore 0.746 inch, and the inspection gage for the relative location of the holes is identical with the one shown in Fig. 25.

In like manner, we must consider the location of these holes from the edge of the components. For simplicity in notation, call the dimension from the lower edge of the piece (in Fig. 28) to the upper edge of the circumference of the lower left-hand hole, *C*. Call the distance from the lower edge of the piece to the bottom edge of the hole, *D*. On the gage, evidently, *C* must be minimum, while *D* must be maximum. The minimum dimension of *C* is equal to 0.998 inch plus half the minimum diameter of the hole (0.375 inch) which amounts to 1.373 inches. The maximum dimension *D* is equal to 1.002 inches minus half the minimum diameter of the hole, which equals 0.627 inch. The diameter of the pins in the gage is equal to the difference between *C* and *D*, which equals 0.746 inch. Therefore, the gage shown in Fig. 25 applies to both Fig. 24 and Fig. 28. Or, to put it in other words, Fig. 24 and Fig. 28 express the same information.

Therefore, in those cases where no tolerances are given for center distance (and this applies equally to locations of holes or grooves or slots, etc.), the minimum clearance must be analyzed, and utilized accordingly to determine the inspection gage requirements, and a suitable minimum clearance must be provided to allow for the inevitable variation in these dimensions. On the other hand, where tolerances are specified on such di-

mensions, these must be analyzed and applied accordingly, to establish the inspection gage dimensions, and the minimum clearance between the holes and studs must be sufficient to prevent interferences. In either case, the basic dimensions should be identical, and the inspection gages would also be identical. For conditions such as those described, experience will teach that the safest plan is to eliminate the tolerances from the component drawings.

The above interpretations of drawings are arbitrary to a certain extent. It would be possible to demonstrate that under certain combinations of conditions, the exact letter of the component drawings would be violated. This is inevitable in this

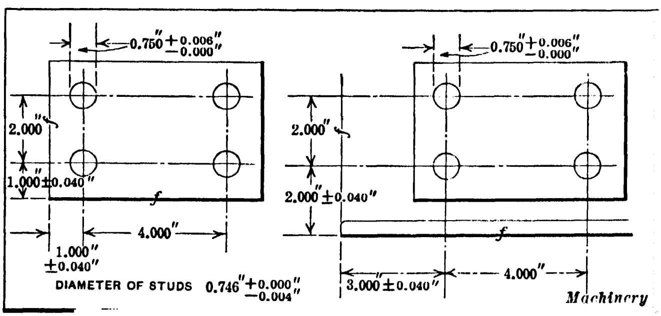


Fig. 29. Another Method of Dimensioning with Tolerance Part shown in Fig. 24

connection. As stated before, if these solutions are accepted, the corresponding interpretations must also be accepted.

Tolerances for "Group" Locations. The same parts, but with different functional conditions, will now be considered. Naturally, the holes in the companion parts must line up sufficiently to enable the studs to pass through. Therefore, the importance of the location of these holes in relation to each other is constant. We will assume, however, that in this case the position of the bracket on the frame is unimportant. The only method of indicating this condition that will be consistent with the general practice of dimensioning discussed heretofore will be to express a tolerance. This is done in Fig. 29. No tolerances are shown in this sketch on the dimensions controlling the relative locations of the holes to each other.

The interpretation of this drawing is that a variation of 0.040 inch, plus and minus, over and above that allowed by the minimum clearance between studs and holes is permitted on the location of the holes as a group. The inspection gage for testing this is shown in Fig. 30. This gage differs from that shown in Fig. 25 only in the addition of the steps on the edges which check the additional tolerance. It is used as follows: When the gage is held against the upper edges of the holes, the minimum lower step of the gage must not extend below the lower edge of the part. When the gage is held against the lower edge of the holes, the lower maximum step must not be above the lower edge of the part. The horizontal locations are checked

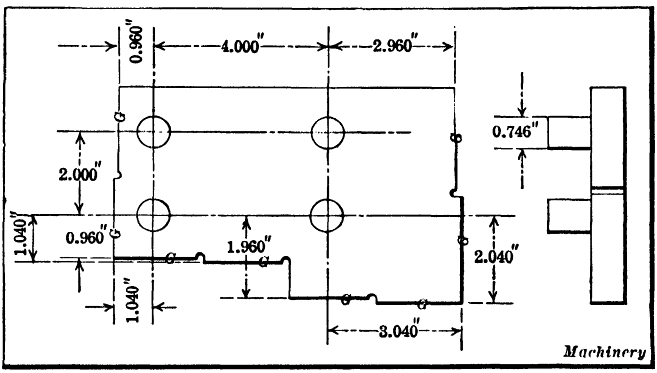


Fig. 30. Functional Gage for the Part shown in Fig. 29

in a similar manner. If the functional conditions permit a liberal variation in one direction (say, horizontal) but not in the other direction (vertical), a combination of the methods of dimensioning and checking meets the situation.

Conditions arise where the locations of holes must be established and checked from other points than a flat surface. This often requires quite elaborate fixture gages. A full understanding of the preceding principles and a careful study of the particular conditions will point the way to a consistent solution of the problem. The present space is not sufficient to go into the subject in greater detail. Simple examples have been purposely selected to indicate and illustrate the general principles involved.

The preceding examples involve maintaining the relative position of several holes with each other in addition to the location of a group as a whole. In those cases where only a single hole is involved which must maintain its position in relation to elementary surfaces, the problem is simple. In most cases it can be solved by the application of methods previously discussed for elementary surfaces. In other cases, the functional requirements may be such as to demand a functional gage similar to those shown in Figs. 25 and 30.

Concentricity and Alignment. The expression of permissible variations in concentricity and alignment introduces another difficult problem. The succeeding examples offer one solution.

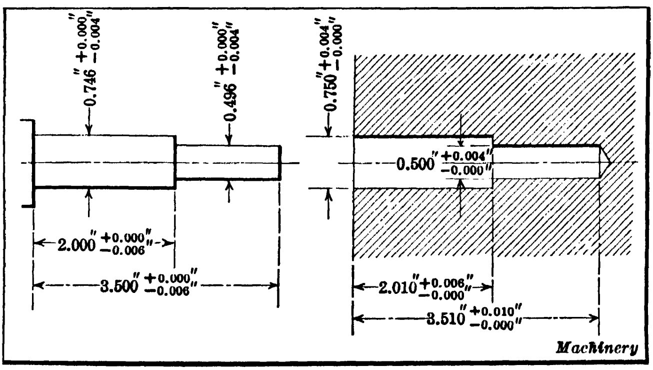


Fig. 31. Methods of dimensioning Holes and Studs to fit

As in the case of the locations of holes, if these solutions are accepted, the corresponding interpretations, expressed in terms of inspection gage requirements, must also be accepted.

We will assume that the stud shown in Fig. 31 must always assemble into the hole shown in the same sketch. In the process of manufacture, a certain amount of eccentricity will develop. If we attempt to give on the component drawings the permissible eccentricity in every case, the drawing will become more and more complicated. The more complicated the drawings become, the greater the possibility of undetected errors. With the following interpretations of the drawings, the conditions of eccentricity are almost automatically covered.

There is a minimum clearance on diameters of 0.004 inch between the parts shown in Fig. 31. Inspection gages to test the concentricity of these parts are functional gages and invade this minimum clearance to a fair amount. In general, this should not be over fifty per cent. The lengths of the studs and depths of the holes do not enter into this discussion. They are elementary surfaces which should be readily maintained and checked. The gages for testing the concentricity of these parts

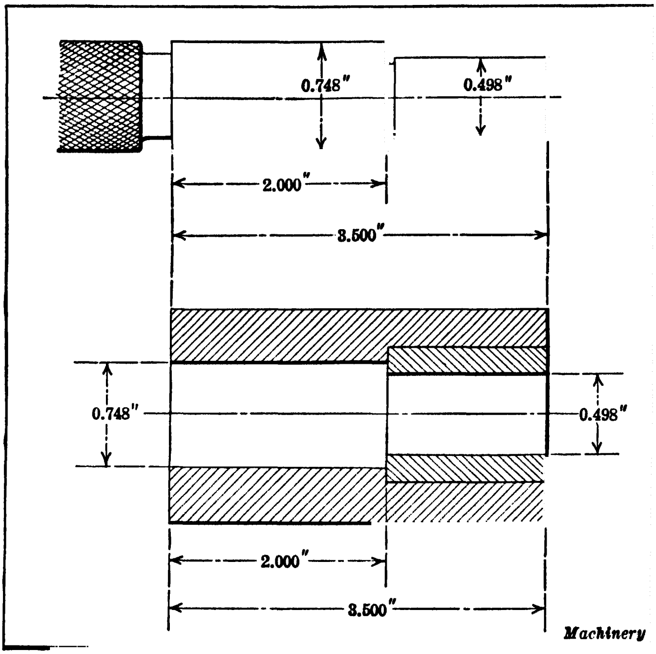


Fig. 32. Functional Gages for Part shown in Fig. 31

are shown in Fig. 32. It will be noted that the diameters invade the minimum clearance by an amount equal to fifty per cent. A somewhat similar condition which involves the alignment of slides, or profile grooves and tongues, has been previously discussed in connection with Fig. 10. Functional gages for such conditions are shown in Fig. 12.

Occasionally, the situation arises where a sub-assembly as a whole must meet such conditions as are described above. This

may entail individual tests for concentricity or alignment on individual component parts of the sub-assembly. The minimum clearances must, therefore, be subdivided proportionately. In such cases, it is good practice to include on the component drawing an outline with the dimensions of the functional gage required to test the conditions of concentricity or alignment. This practice will eliminate many arguments in the course of future production.

Gears. Gear teeth offer another problem of composite surfaces. In general the tolerances on the tooth forms can best be given by specifying the permissible amount of backlash between the pair. No tolerances should ever be given on pitch diameters of gears. Specifying a limit on the backlash makes it possible to eliminate all compound tolerances. Furthermore, the most effective inspection of the gears is obtained by measuring this backlash with the gears at a fixed center distance. All the foregoing examples are comparatively simple ones. They should, however, be sufficient to indicate the manner in which a component drawing with tolerances should be dimensioned.

As stated previously, it is seldom possible at the very start to collect and record on the component drawings all of the detailed information which belongs there. The development of tools, gages, and other equipment and the final solution of many of the manufacturing problems will make apparent omissions and errors. Therefore, the component drawings should not be considered as complete until the product is actually being produced in strict accordance with them. This requires that the designer, responsible for the accuracy of the drawings, keep in close touch with both the designers of the manufacturing equipment and the various manufacturing departments in order to keep these component drawings up to date.

CHAPTER VI

PRACTICE IN MAKING COMPONENT DRAWINGS

As a practical and specific illustration of the principles governing the dimensioning of component drawings set forth in the preceding chapter, a small unit assembly showing the percussion firing mechanism for a large cannon is taken as an example. This particular mechanism is chosen because it is composed of a small number of parts; also because it contains several examples of comparatively unusual conditions. In studying the various component or detail drawings to be referred to, the relation between the methods of dimensioning, the tolerances and clearances specified, and the functional requirements of each part should be carefully considered.

Drawing of Firing Mechanism Assembled. The assembly of this mechanism is shown in Fig. 1. The operation is as follows: The firing mechanism container assembled must be withdrawn before the breech of the cannon can be opened, and cannot be replaced until the breech is closed. (The safety mechanism controlling this is not shown on this drawing.) While this assembled container is being withdrawn, a primer *A* is inserted in the primer extractor. This primer is held in place by the pressure of the firing pin guide spring acting against the firing pin guide *B*. After the breech has been closed again, the container *C* with the primer is inserted into the housing *D* and screwed home by hand. The primer must seat tightly on the sharp taper in the spindle plug *E*. A lanyard is attached to the striker *F* with a connection that slips off when the end of the striker is withdrawn beyond the end of the container cover *G*, thus allowing the striker to move forward at the proper moment under the impulse of the firing spring *H*. The firing pin transmits the blow of the striker to the primer, thus detonating it and igniting the charge in the cannon.

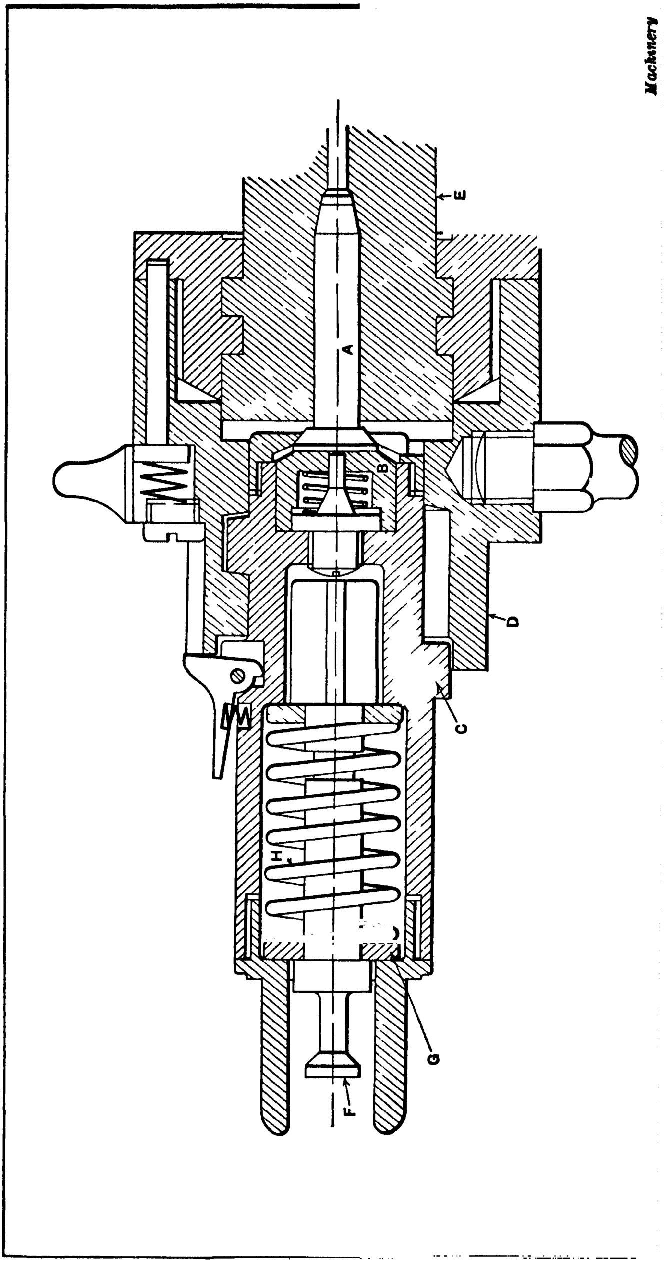


Fig. 1. Firing Mechanism assembled

Functional Requirements of the Mechanism. The following functional conditions must be maintained: The primer must be seated in the spindle plug in such a manner that no gases can escape when the gun is fired. Any leakage of these gases, which are at a very high temperature and under high pressure, will quickly erode or burn out the parts of the mechanism, thus destroying its effectiveness. This requires that the surfaces of the seat for the primer be smooth and that its dimensions be maintained within close limits. The blow imparted by the striker must be sufficient to insure that the primer will always be detonated, since the sole object of the mechanism is to detonate the primer. In order to insure this result, the firing pin must always protrude, in operation, a certain minimum distance (determined by experiments), while, in order not to pierce the primer cup, it must never protrude beyond a certain maximum distance (also determined by extensive experiments). The various unit assemblies of the mechanism must be interchangeable in order to allow quick replacements in service — a vital requirement. As far as proves economical, the various component parts of the unit assemblies should be interchangeable to permit ready repairs in service. Unless noted otherwise, the parts of this mechanism must be interchangeable. These are the most important of the functional requirements. Others will be discussed as they arise in connection with the details.

Drawing of Firing Pin Guide. A detail drawing of the firing pin guide is shown in Fig. 2. The outside diameter is 0.782 inch plus 0.000, minus 0.003. This guide must be an easy slide fit in the container. It has a minimum clearance of 0.002 inch, as will be seen by a comparison with that part of the container (see Fig. 7) which receives the guide. With a tolerance of 0.003 inch on each part, it has a maximum clearance of 0.008 inch. With a reasonably smooth finish, such as that obtained by a finishing cut on the guide and a finish-reaming operation on the hole in the container, these clearances will maintain the conditions required.

The firing pin must be an easy slide fit in the guide. The diameter of the firing pin hole is 0.118 inch plus 0.003, minus

0.000. The diameter of the firing pin is 0.117 inch plus 0.000, minus 0.003; hence the minimum clearance is 0.001 and the maximum clearance (with tolerance of 0.003 on each part), 0.007 inch. With a reamed finish in the hole and a finishing cut on the pin, these clearances will maintain the proper conditions.

The diameter of the large counterbore in the rear of the guide is 0.584 inch plus 0.003, minus 0.000. The flange of the firing pin must be an easy slide fit in this counterbore. The diameter of the flange is 0.582 inch plus 0.000, minus 0.003; therefore the minimum clearance is 0.002 and the maximum clearance, 0.008

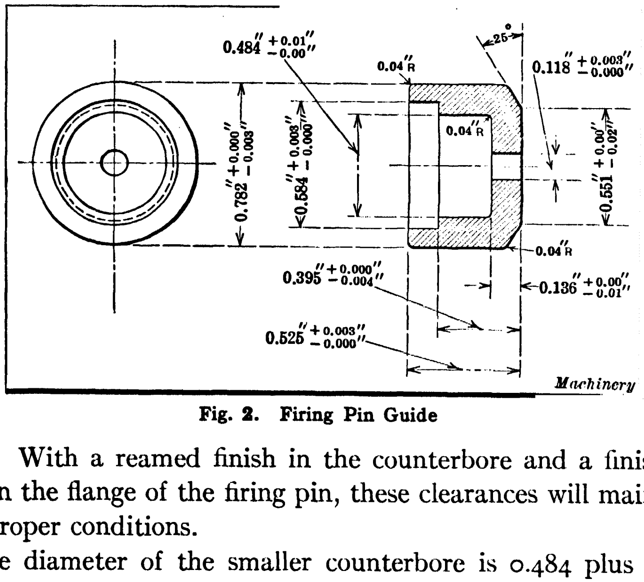


Fig. 2. Firing Pin Guide

inch. With a reamed finish in the counterbore and a finishing cut on the flange of the firing pin, these clearances will maintain the proper conditions.

The diameter of the smaller counterbore is 0.484 plus 0.01, minus 0.00. This counterbore contains the firing pin guide spring. The minimum clearance is 0.020 and the maximum clearance 0.040 inch. It is apparent that this surface is of minor importance. The only limit to the increase in diameter of this surface is controlled by the width of shoulder at its mouth which is needed to act as a stop for the firing pin. The basic width of this shoulder is 0.05 inch; the tolerance on the counterbore diameter is 0.01, thus reducing the effective width of the shoulder by 0.005 inch. The tolerance specified should be sufficient to enable this counterbore to be finished in one cut. No finishing

operations are necessary on this surface either for smoothness or accuracy.

Exception to General Rule for Basic Dimensions. The length of the guide (Fig. 2) is 0.525 inch plus 0.003, minus 0.000. This dimension is an exception to the general rule of making the basic dimension represent the maximum metal conditions, because of the functional conditions which must be maintained in this case. When the firing pin and the guide are seated solidly in the container, the face of the guide and the end of the firing pin should be as nearly flush as possible. Under no conditions must the firing pin project, because any such projection makes possible a premature explosion of the primer. The basic dimensions on the firing pin and guide are identical for this point, thus making these surfaces flush under basic conditions. The direction of the tolerances in each case is such that the pin can never project. This method of dimensioning, therefore, adheres to the principle of making the basic dimensions represent the danger point, while the direction of the tolerance is such as to move away from this danger point.

On the other hand, there is another danger point in the other direction, although not as serious a one as the first. In such cases, the basic dimension should always represent the more dangerous point, while the tolerances should limit the extent of the other. In this case, the second danger point is that the end of the firing pin should be held as nearly flush with the face of the guide as possible so as not to form a pocket into which the primer cup might be forced under firing conditions. If this happens, it is very difficult to remove the exploded primer. This may retard the rate of fire and possibly put the gun out of action. The tolerances on these dimensions limit the depth of this pocket to 0.006 inch which is as great as is considered safe. The front face of the guide must be smooth; a polished surface is desirable, as this facilitates the insertion and removal of the primers.

The dimension from the bottom of the large counterbore to the front face is 0.395 inch plus 0.000, minus 0.004. This dimension controls the protrusion of the firing pin and is, therefore, the dimension to be maintained. Experiments show that

the firing pin should protrude at least 0.026 inch in order to insure detonation, while it should not protrude over 0.034 inch or there will be danger of piercing the primer cup; therefore, the corresponding length of the firing pin is made 0.421 inch which gives the minimum protrusion of 0.026 inch while the tolerance of 0.004 inch applied to each part limits the maximum protrusion to 0.034 inch.

Maintaining a Common Locating Point. Inasmuch as the important functional dimensions of length are given from the front face, the bottom of the small counterbore is also located from that surface so as to maintain one common locating point. This surface is unimportant; a dimension of 0.136 inch plus 0.00, minus 0.01 is specified, which should give wide enough limits to enable it to be machined in a single cut.

The bevel at the front of the guide is provided to assist in the insertion of the primer. The diameter of the intersection of this bevel with the front face is given as 0.551 inch plus 0.00, minus 0.02. These limits should be wide enough to meet any normal manufacturing conditions. The surface of the bevel must be smooth; a polished surface would be desirable. The angle of the bevel is given as 25 degrees. No tolerance is specified, as the permissible variation is controlled by the tolerance given for the face. The angle of the corresponding surface of the primer extractor is 14 degrees. The angle on the guide is made greater to insure that the forward corner of the guide will not project above the bottom of the primer slot in the extractor. Any such projection would interfere with the ready insertion of primers.

No tolerances are given for the radii of the corners of the guide. In the first place, a reasonable variation is already established for them by the tolerances given on other dimensions. In the second place, their exact contour is of no importance, their purpose being to remove the sharp corners. A straight bevel of the same dimensions would be as effective.

Drawing of Firing Mechanism Container Cover. The thread of the container cover screws into the container and must be set up as tightly as possible. The outside or major diameter

of the thread is 1.125 inch plus 0.000, minus 0.008 (see Fig. 3). The pitch diameter is 1.0979 inch plus 0.000, minus 0.004. The minimum clearance is 0.000 and the maximum clearance on the pitch diameter, 0.008 inch, as will be seen by comparing Figs. 3 and 7. This tolerance should be kept as small as normal manufacturing methods will permit.

The diameter of the flange is 1.25 inch plus 0.00, minus 0.01. This surface is an atmospheric fit and of little importance, as regards either smoothness or accuracy; hence it should be completed in a single machining operation. The diameter of the stem is 1.10 inch plus 0.00, minus 0.01. This surface is an

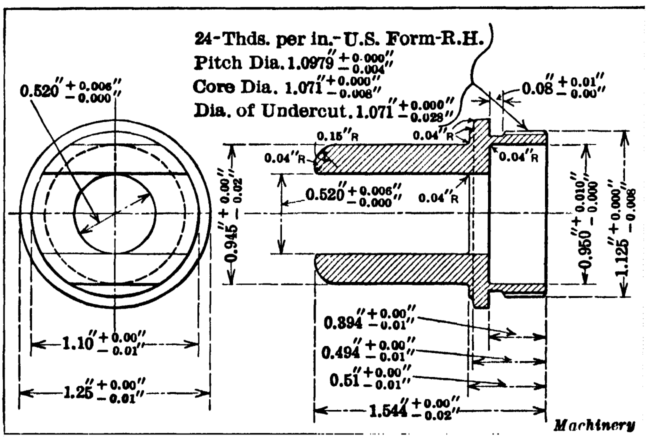


Fig. 3. Firing Mechanism Container Cover

atmospheric fit and should be machined in a single operation. The distance across the flats on the stem is 0.945 inch plus 0.00, minus 0.02. This surface is for the wrench used in assembling and is of little importance. It should be machined in a single operation by a straddle-milling tool.

The diameter of the hole and the width of slot is 0.520 inch plus 0.006, minus 0.000. These surfaces are for the striker and lanyard connection. They should be as smooth as careful reaming and finish-milling operations will leave them. The hole and the slot must be matched so that no shoulder will be left at their intersection, which would retard the striker in its action. This

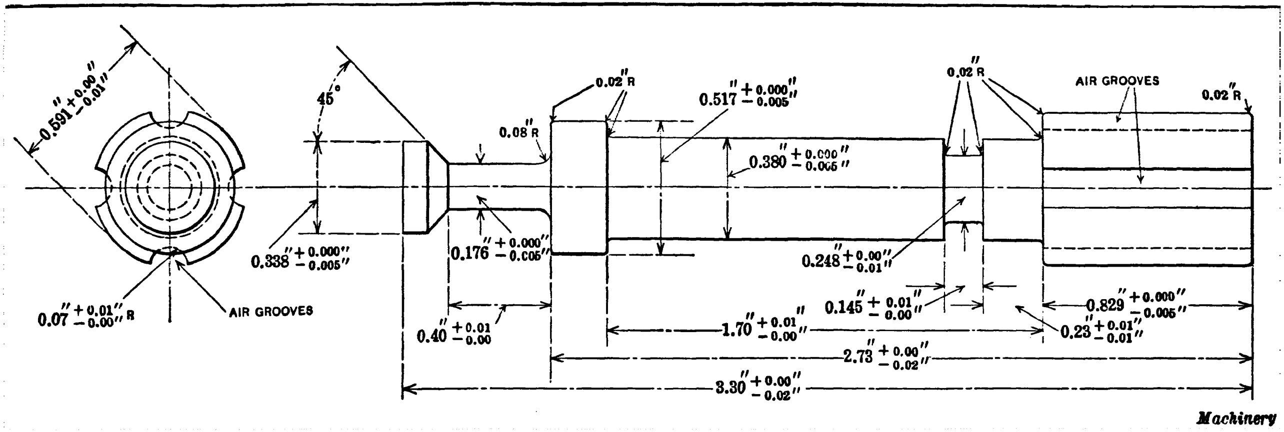


Fig. 4. Striker of Firing Mechanism

will probably require a slight filing operation to match the cuts properly. The tolerance given should be sufficient to meet all normal manufacturing conditions. The diameter of the counterbore is 0.950 inch plus 0.010, minus 0.000. This counterbore forms a seat for the spring seat washer and is relatively unimportant. It should be finished in a single operation with a counterbore. The surface left by such a tool will be as smooth as is necessary.

Length Dimensions Given from Logical Working Point. The dimensions of length are all given from the front surface. From a functional viewpoint, there is little choice between this surface and any of the others. The manufacturing operations will be simplified by the maintenance of one common work-

ing point. As the front surface is the logical working point, this has been chosen.

The length of the thread is 0.394 inch plus 0.00, minus 0.01. The width of the recess is 0.08 inch plus 0.01, minus 0.00. The requirements of these dimensions are that there shall be sufficient threads to hold the cover in position and that the length of this stem shall be less than the depth of the recess in the container, as the cover must always seat on its flange. The depth of the recess into which the thread projects may extend about 0.01 inch below the bottom of the threads to give a suitable clearance for threading. Also, the end of the stem and edge of the recess may be beveled about thirty degrees to facilitate this operation. The depth of the counterbore is identical with the length of the threaded stem. This depth is of relatively small importance.

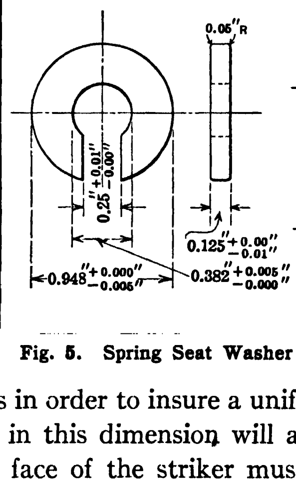
The location of the rear face of the flange is 0.494 plus 0.00, minus 0.01. This surface is an atmospheric fit and should be finished in a single operation. The bottom of the wrench cuts is 0.51 plus 0.00, minus 0.01. This is a clearance surface of little importance. It is left above the rear surface of the flange to eliminate all matching operations. The bottom of the slot is located by these same dimensions, and its surface is of equal unimportance.

The length over all is 1.544 inches plus 0.00, minus 0.02. The rear surface of the cover is an atmospheric fit of minor importance. No tolerances have been specified for any of the radii, as their exact contour is of no importance. Their purpose is to remove the sharp corners. Furthermore, sufficient variations have been established for these radii by the tolerances on other dimensions.

Drawing of Striker. The diameter of the front end of the striker (see Fig. 4) is 0.591 inch plus 0.00, minus 0.01. This surface must clear the counterbore in the container (see Fig. 7). The minimum clearance is 0.019 inch and the maximum clearance 0.039 inch. The radius of the air grooves is 0.07 inch plus 0.01, minus 0.00. No finishing cuts are required on these surfaces. The stem which has a diameter of 0.38 inch plus 0.000,

minus 0.005, must be a free sliding fit in the spring seat washers. The minimum clearances are 0.002 inch and the maximum 0.012 inch. This stem must have a smooth surface, such as will be secured by a finishing tool.

The rear shoulder which has a diameter of 0.517 inch plus 0.000, minus 0.005, must be a free sliding fit in the cover. The minimum clearance is 0.003 inch and the maximum clearance 0.014 inch. This surface must be as smooth as a careful finishing cut will leave it. The length of the front end (0.829 inch plus 0.000, minus 0.005) should be held within reasonably close



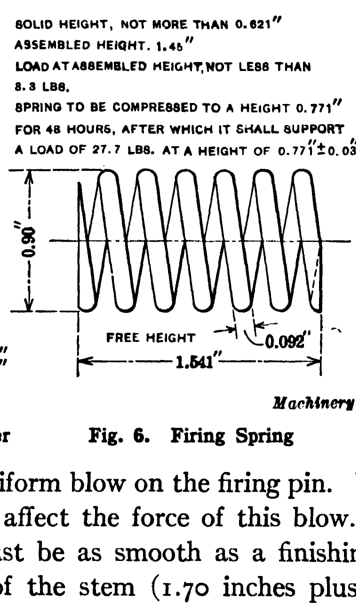


Fig. 5. Spring Seat Washer **Fig. 6. Firing Spring**

limits in order to insure a uniform blow on the firing pin. Variations in this dimension will affect the force of this blow. The front face of the striker must be as smooth as a finishing cut will leave it. The length of the stem (1.70 inches plus 0.01, minus 0.00) should also be held within reasonably close limits, as it controls, to a certain extent, the force of the blow of the striker. This stem could be machined with a form tool, the roughing tool being made to form the neck for assembling the washers. The neck is, therefore, located from the front end of the stem, the dimension being 0.23 inch plus 0.01, minus 0.01. The width is 0.145 inch plus 0.01, minus 0.00. These limits should be adequate to permit this groove to be finished with a roughing tool without any unnecessary refinements.

The location of the rear shoulder from the front end (2.73 inches plus 0.00, minus 0.02) and the width of the bottom of the groove (0.40 inch plus 0.01, minus 0.00) are relatively unimportant. The surfaces, however, must be reasonably smooth ones such as are obtained with a finishing tool. These limits should be sufficient for all manufacturing purposes. The length over all (3.30 inches plus 0.00, minus 0.02) is also relatively unimportant. A sufficiently smooth surface for the rear end will be obtained with a cutting-off tool.

No tolerances are given for the 45-degree bevel at the rear end, nor for the radii, because none are required. A reasonable variation is already established by tolerances given on other dimensions. Sufficiently accurate radii will be obtained by touching with a file the various corners which are not broken by form tools, to remove the sharp edges.

Drawing of Spring Seat Washer. If a large number of spring seat washers (see Fig. 5) were to be manufactured, they might be made in a punch and die. The surface obtained in a well made sub-press die would be sufficiently smooth, but the surface obtained on the usual punch press in an open die would probably require some polishing. For a small number of parts, bar stock could be used. The surface obtained with a finishing tool would be satisfactory.

The hole must be a free sliding fit on the stem of the striker. The minimum clearance is 0.002 inch and the maximum clearance 0.012 inch. A surface equal to that obtained with a reamer should be secured. The width of the assembling slot is unimportant. The faces of the washer are of but minor importance. The original surface of flat stock, if that is used, or the surface obtained with a cutting-off tool, if bar stock is used, will be satisfactory.

Tolerances are not needed for the radius of the corners, but enough of the corner must be removed to permit the washer to seat properly in the counterbore in the cover. This corner may be removed on a polishing wheel or with a file in the lathe.

Drawing of Firing Spring. No tolerances are given on the dimensions of the firing spring (see Fig. 6), because the functional

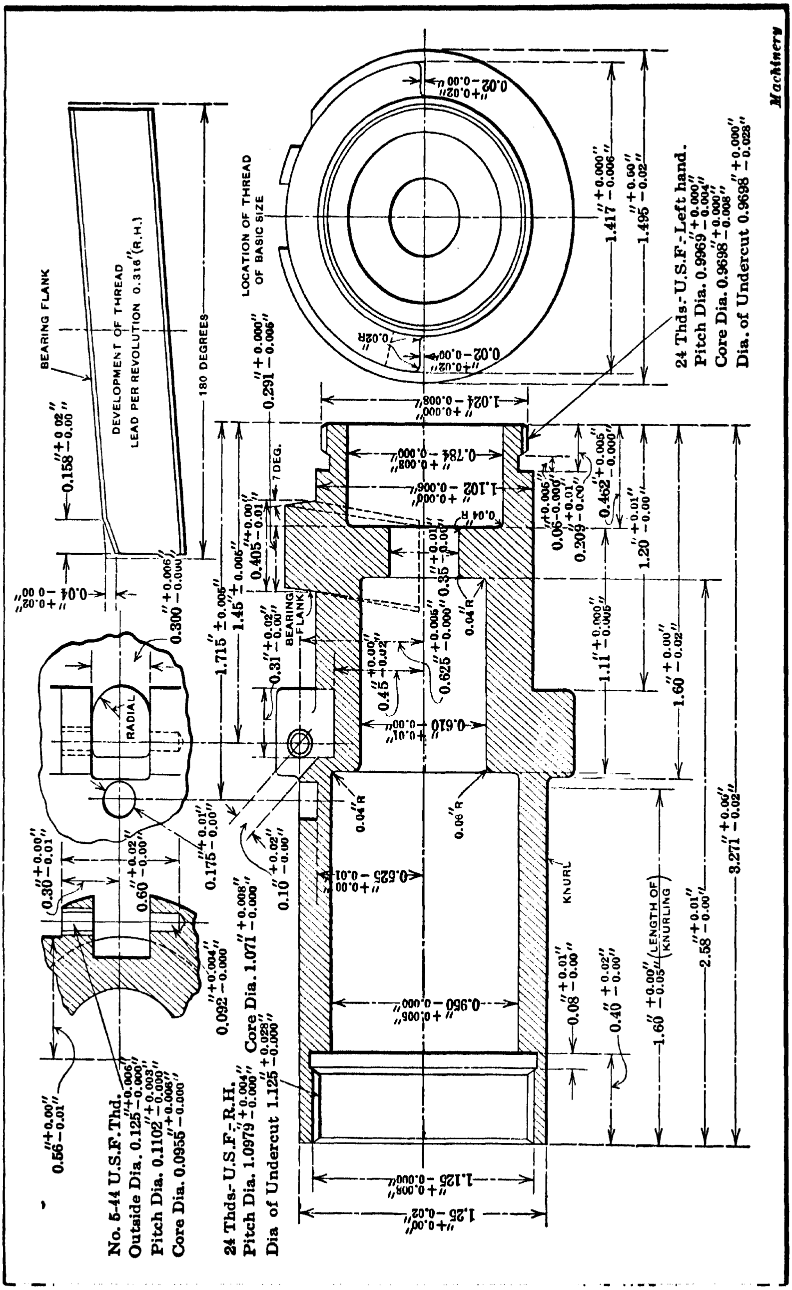


Fig. 7. Firing Mechanism Container

requirements are covered by the weight specifications, and the manufacturer is allowed reasonable latitude in these dimensions as long as the weight requirements are maintained. The dimensions given are nominal. A variation of 0.005 inch in the diameter of the wire, or of 0.030 inch in the diameter of the coils or free length of the spring will be of no moment. If these tolerances were expressed on the drawing, some manufacturer would complain that the weight specifications would not allow him to take full advantage of them, and would seek to have the weight requirements altered or removed. These weight conditions are the essential ones, as they control the force of the blow on the primer. A minimum load of 3.3 pounds is required at the assembled height of 1.45 inches. A load of 27.7 pounds is required at a height of 0.771 inch plus 0.03, minus 0.03. By thus specifying loads at two heights, the strength of the spring is very closely controlled.

Drawing of Firing Mechanism Container. The container is shown in Fig. 7. The housing thread (which has an outside diameter of 1.417 inches plus 0.000, minus 0.006) is a special thread and will undoubtedly be milled. It must be a very free fit in the housing, as the container is inserted and removed every time the gun is fired. It must assemble readily, even if a certain amount of dirt and grit is present. The minimum clearance is 0.008 inch and the maximum clearance 0.020 inch. The surfaces must be smooth. A finish-turning or milling cut will be satisfactory. It will be necessary to match the turning and milling cuts where the bottom of this thread matches the cylindrical portion of the container with a file after the part is machined.

The thread for the primer extractor (outside or major diameter 1.024 inches plus 0.000, minus 0.008) must be left hand to prevent the primer extractor from unscrewing as the mechanism is removed from the housing. The minimum clearance is 0.000 and the maximum clearance on the pitch or effective diameter, 0.008 inch. The primer extractor must be screwed home as firmly as possible, and the variations on these threads should be kept as small as normal manufacturing methods will permit.

The small counterbore in the rear end (diameter 0.610 inch plus 0.01, minus 0.00) is for clearance and is unimportant. It should be finished at a single operation of a counterbore. The large counterbore in the rear end (diameter 0.950 inch plus 0.005, minus 0.000) must be a free sliding fit for the washer and should be reamed. The minimum clearance between the hole having a diameter of 0.35 inch plus 0.01, minus 0.00, and the firing pin is 0.05 inch, while the maximum clearance is 0.07 inch. This surface is unimportant and should be machined by a single drilling operation. The diameter of the counterbore in the front end is 0.784 inch plus 0.003, minus 0.000. This surface must be an easy sliding fit for the guide and requires a careful finish-reaming operation. The length over all (3.271 inches plus 0.00, minus 0.02) is relatively unimportant, yet both the front and the rear faces must be smooth, as they form the seats for the cover and primer extractor. The majority of the length dimensions are located from the front face. A few are given from the rear end because of manufacturing considerations. The remainder are given from intermediate points because of the functional requirements of the mechanism.

The length of the thread for the extractor is 0.209 inch plus 0.01, minus 0.00, and the width of the under-cut, 0.06 inch plus 0.005, minus 0.000. The requirements of these dimensions are that there shall be sufficient threads to hold the extractor properly and that the length of the stem be always long enough to permit the extractor to seat on the front face of the container.

The bottom of the large counterbore, which is 1.11 inches plus 0.000, minus 0.005, from the firing pin seat, is an important functional surface and should be finished by a special operation, locating from the firing pin seat. This dimension controls, to a great extent, the force of the blow of the striker. The location of the housing thread is also controlled from the firing pin seat. This dimension (0.291 inch plus 0.000, minus 0.005) controls the angular position of the mechanism when it is screwed home in the housing. A plus variation on this dimension might prevent the mechanism from locking. The width of the housing thread is 0.405 inch plus 0.00, minus 0.01. The

rear surface or flank of this thread is a bearing surface and must be smooth. A corner of this rear flank is beveled with a file to facilitate entering the housing (see view showing development of thread). The length of bevel is 0.158 inch plus 0.02, minus 0.00, and the width of bevel 0.04 inch plus 0.02, minus 0.00. This should give sufficiently liberal tolerances for all manufacturing purposes. Double this tolerance could be given, however, if necessary.

The latch-pin and spring holes are both located from the front face of the container, as this is the logical locating point for the drill jig. The distance from the latch-pin hole to the

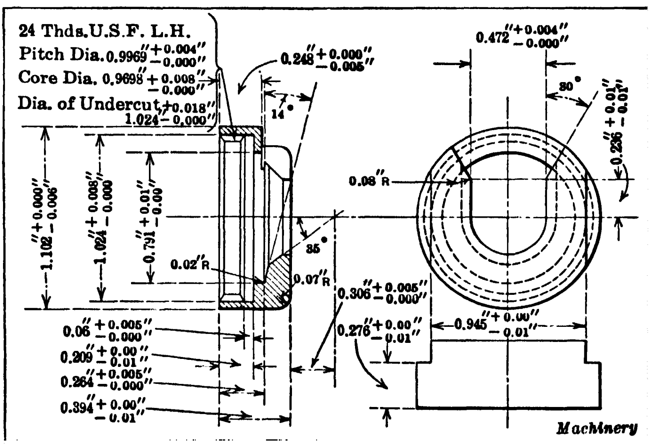


Fig. 8. Primer Extractor

center of the container is 0.625 inch plus 0.005, minus 0.000. A minus variation on this last dimension would develop interference between the bottom of the slot and the latch. The latch-pin thread is a standard No. 5-44 A.S.M.E. thread. Taps should be avalaible from stock from any reliable tap manufacturer. This is a fine thread and should be held as close to size as normal manufacturing conditions will permit.

The distance to the cut on the left side of the flange is 0.30 inch plus 0.00, minus 0.01, and the height from the bottom of the cut is 0.56 inch plus 0.00, minus 0.01. The requirements of this cut are that the cutter shall not gouge the knurled handle

by cutting too deeply and that the tap shall not gouge the bottom of this cut. The limits specified give the greatest permissible variations under maximum metal conditions and should be great enough to allow this cut to be machined in a single operation. The width of the latch slot is 0.300 inch, plus 0.006, minus 0.000. This surface must be reasonably smooth so as to maintain an easy action of the latch. The minimum clearance is 0.003 inch and the maximum clearance, 0.013 inch. With the proper surfaces, these clearances will maintain the desired conditions.

The location of the bottom of the slot from the center of the container is 0.45 inch plus 0.00, minus 0.02. A plus variation on this dimension would develop interference with the latch. The surface of the bottom and ends of this slot is not important and requires no finishing cuts. The cuts on the side of the slot must be matched to provide a smooth bearing for the latch.

The ends of the housing thread are 0.02 inch plus 0.02, minus 0.00, from the center of the container. These surfaces require no finishing cuts. The length of the knurling is 1.60 inches plus 0.00, minus 0.05. A scale measurement will be sufficient to check this dimension. No tolerances are given on the various radii or angles, as none are required. Tolerances on other dimensions establish liberal variations for these surfaces.

Drawing of Primer Extractor. The outside diameter of the primer extractor (see Fig. 8) which is 1.102 inches, plus 0.000, minus 0.006, should approximately match the corresponding diameter on the container shown in Fig. 7. The surface should be reasonably smooth. The diameter of the recess for the firing pin guide (0.791 inch, plus 0.01, minus 0.00) is clearance and is unimportant. The depth (0.264 inch, plus 0.005, minus 0.000) is more important, as it controls the amount of surface which engages the head of the primer. A finish cut will be required on this surface.

The width of the extractor slot (0.472 inch, plus 0.004, minus 0.000) is an important dimension and the surface must be smooth. A finish cut will be required. The bevel at the end of this slot is at an angle of 30 degrees and is located from the

center of the extractor at a distance of 0.236 inch, plus 0.01, minus 0.01. The exact dimensions of the bevel are unimportant, as it is provided merely to facilitate assembling the primer. The surfaces must be smooth, however, even if an extra filing operation is needed to match the cuts.

The distance across the flats (0.945 inch, plus 0.00, minus 0.01) is for the wrench used in assembling and is unimportant. No finish cuts are required. The length of the extractor is 0.394 inch, plus 0.00, minus 0.01. The front face must clear the rear face of the spindle plug when the primer is seated; therefore, no plus variation is permissible. Any great minus variation will weaken the extractor. The tolerance given should be liberal enough for all normal manufacturing purposes. Both the front and rear surfaces should be reasonably smooth. This will require finishing cuts.

The depth of the tapped hole is 0.209 inch, plus 0.00, minus 0.01, and the width of the thread under-cut, 0.06 inch, plus 0.005, minus 0.000. Enough threads must be secured to hold the extractor firmly in position, yet the depth must be shallow enough to permit the extractor to seat on the front face of the container. It is permissible to make the depth of the thread under-cut not over 0.005 inch below the bottom of the threads to provide clearance for the tap. A greater diameter of under-cut than 1.042 inch (maximum outside or major diameter of thread or 1.032 inch plus 0.01 in diameter allowed for tap clearance) would weaken the extractor to such an extent that it would not be safe to use it in service.

The location of the bottom of the primer slot from the rear face is 0.248 inch, plus 0.000, minus 0.005. This surface should never come below the corner on the firing pin guide, for if it did, it would be difficult to insert the primer. The surface should be smooth and all corners about this slot must be carefully broken.

Dimensioning to Prevent Compound Tolerances. The countersink which merges into the beveled surface on the under side of the primer head is located from a theoretical point, where its angle of 35 degrees intersects the center line of the extractor.

The distance from this intersecting point to the front face is 0.306 inch, plus 0.005, minus 0.000. Such a method of dimensioning is necessary to prevent compound tolerances. It will be noted that no dimensions are given for the intersections of this angle with the primer slot or bottom of the recess. Such dimensions are unnecessary and could not be measured directly in any event. The dimensions given locate this surface definitely and completely. It will be necessary for the manufacturer to compute the diameters on this countersink to suit his own

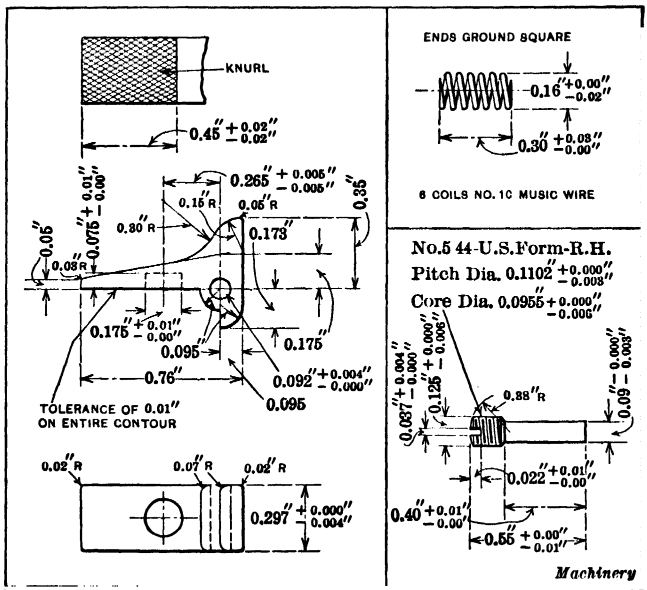


Fig. 9. Locking Latch, Spring and Pin

particular needs. This surface must be smooth and will require a careful finishing operation.

No tolerances are given on any of the angles or radii because none are needed. Sufficient variation on these surfaces is permitted by the tolerances given on other dimensions.

Drawing of Locking Latch, Spring, and Pin. The surfaces of the locking latch (Fig. 9) must be smooth, as they bear on the sides of the slot in the container. This part has a tolerance of minus 0.01 inch on the entire contour. This means that the

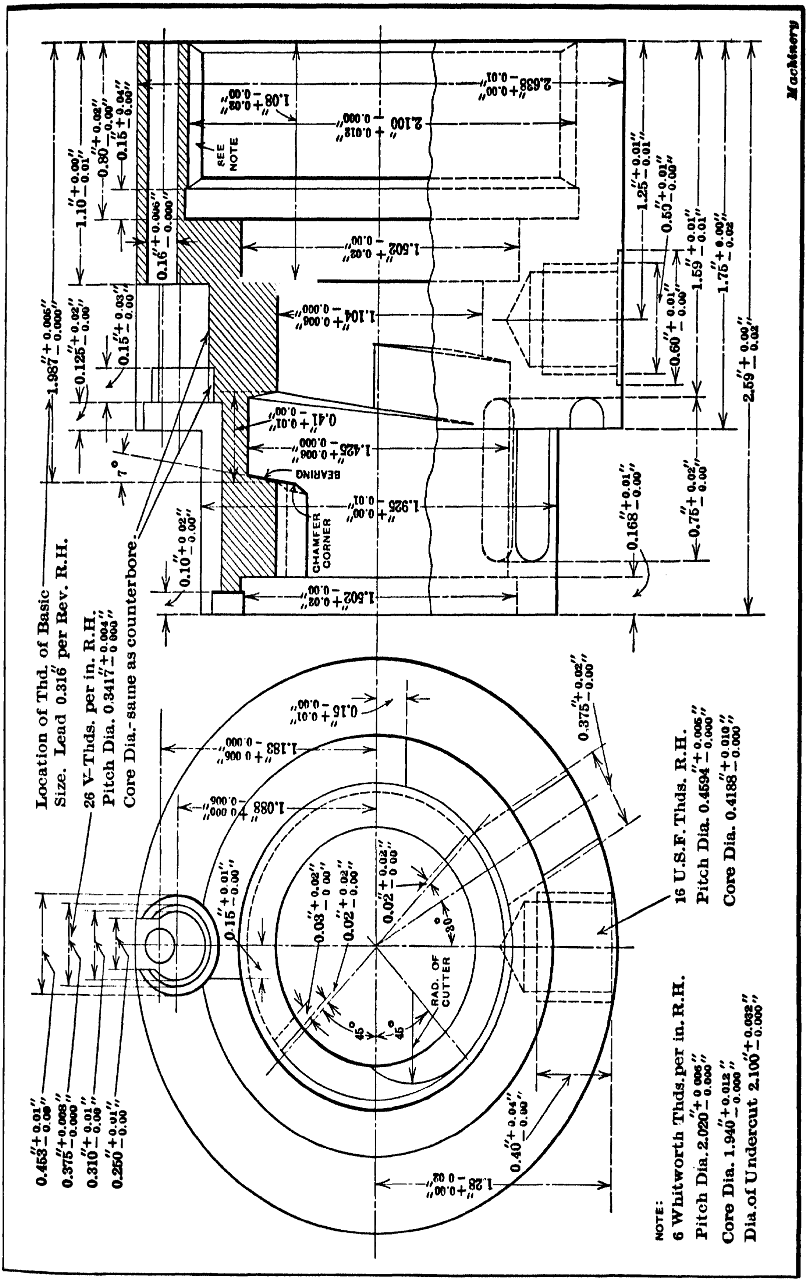


Fig. 10. Housing of Firing Mechanism

piece may vary 0.01 inch normal to the profile at any point in the direction that will make the piece smaller, or, in other words, any variation from the normal dimensions must remove more metal. The diameter of the pin hole (0.092 inch, plus 0.004, minus 0.000) corresponds with the pin hole in the container. The diameter of the spring hole (0.175 inch, plus 0.01, minus 0.00) also corresponds with the spring hole in the container.

The locking latch spring (Fig. 9) is a part of minor importance. It is made of No. 10 music wire, and no tolerance is specified for its diameter. This means that commercial music wire bought in the open market will be satisfactory. No difficulty should be experienced in maintaining the limits given.

The thread of the locking latch pin is a No. 5-44 U. S. form. This is a standard A.S.M.E. thread, and dies should be available in stock at any reliable die manufacturer's. After this pin is assembled into the container, the end thread of the tapped hole in the container should be upset slightly with a punch to prevent this pin from falling out. It should be understood that it is permissible to bevel at both ends of the thread to facilitate the threading. The surface of the stem forms a bearing for the latch and should receive a finish cut. This part should be completed in a single operation on a screw machine.

Drawing of the Housing. The outside diameter of the housing (Fig. 10) is 2.638 inches, plus 0.00, minus 0.01. This is an atmospheric fit and requires no finishing cut, which also applies to the shoulder, the diameter of which is 1.925 inches plus 0.00, minus 0.01. The Whitworth thread, the full or major diameter of which is 2.100 inches, plus 0.012, minus 0.000, must assemble on the hinged collar (Fig. 11). The Whitworth form of thread is used to suit other types of firing mechanisms now in service; otherwise the U. S. form of thread would be preferable.

The counterbore in the front end (diameter 1.502 inches, plus 0.02, minus 0.00) must clear the spindle plug. No finishing cut is required. The counterbore in the rear end of the same size must clear the flange on the container. The minimum clearance is 0.007 inch and the maximum clearance, 0.047 inch. No finish cut is required. The full or major diameter of the con-

tainer thread is 1.425 inches, plus 0.006, minus 0.000. A sector of this thread is removed to permit the assembly of the container. All of these surfaces require finishing cuts. The rear flank is the bearing flank and the most essential. The requirements were previously given in connection with the firing mechanism container. The front face of the housing should be reasonably smooth, as it seats against the hinged collar and is the most important working point for other machining operations.

The depth of the Whitworth thread is 0.80 inch, plus 0.02, minus 0.00. The hole must be deep enough for the hinged collar,

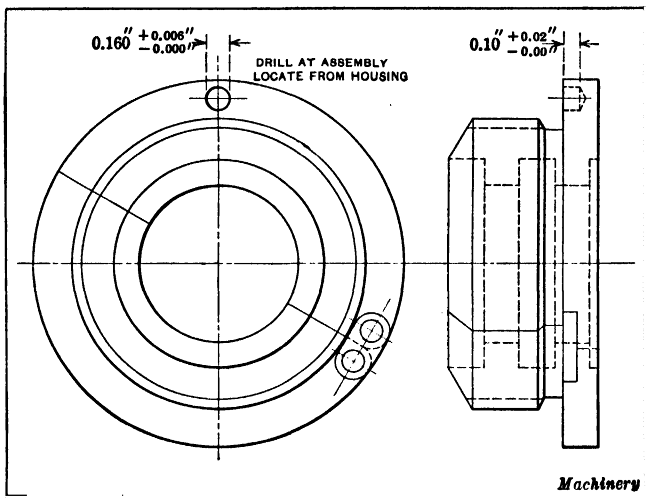


Fig. 11. Hinged Collar assembled

and enough threads must be maintained to hold the firing mechanism in position during the firing of the gun. This thread is subjected to a considerable strain at this time. The depth of the counterbore in the front end is 1.08 inches, plus 0.02, minus 0.00. This surface must clear the end of the spindle plug. No finish cut is required.

The location of the thread for the container is 1.987 inches, plus 0.005, minus 0.000 from the front end. This is an important functional dimension and must be carefully watched, as it controls the angular position of the firing mechanism when

it is screwed home. A minus variation on this dimension would prevent the mechanism from locking. A slot is shown in the lower right-hand side of the housing for the safety mechanism. The safety bar should be a very free fit in this slot. The slot is 1.59 inches, plus 0.01, minus 0.01 from the front end; the length, 0.75 inch, plus 0.02, minus 0.00; and the width, 0.375 inch, plus 0.02, minus 0.00. The surface in the slot should be reasonably smooth. A tapped hole, having a full or major diameter of 0.50 inch, plus 0.01, minus 0.00, is shown in the bottom of the housing for the firing mechanism pin. It is permissible to run the tap drill below the thread, provided that this drill does not break through into the hole in the center of the housing.

A recess is milled in the rear face of the housing to engage the locking latch. This recess allows for a possible variation in the locked position of the container of 90 degrees. The tolerances given on the various controlling dimensions will permit a variation of approximately 30 degrees. The variations on the primer plug and the primer will permit approximately 30 degrees more. This leaves the remaining 30 degrees to allow for wear. The depth of the recess is 0.10 inch, plus 0.02, minus 0.00 and the ends of the recess are located 0.15 inch, plus 0.01, minus 0.00 from the center lines through the rear face, 90 degrees apart.

The hole and counterbores for the collar-catch (shown in Fig. 12) are located from the center of the housing because these holes will be drilled in a jig which should locate the housing centrally. The counterbores are 1.088 inches, plus 0.000, minus 0.005, and the hole, 1.183 inches, plus 0.005, minus 0.000 from the center line (see end view Fig. 10). The diameter of the hole is 0.16 inch, plus 0.006, minus 0.000. This hole should be a free sliding fit for the stem of the collar-catch. The minimum clearance is 0.002, and the maximum clearance, 0.014 inch. The full or major diameter of the tapped hole is 0.375 inch, plus 0.008, minus 0.000, and the pitch diameter, 0.3417 inch, plus 0.004, minus 0.000. No core or minor diameter is given, as the small counterbore, which is a few thousandths inch larger

then the theoretical core diameter, limits the height of the threads. The V-form of thread is used to obtain as great an area of contact as possible. After assembly of the collar-catch screw, the metal should be upset slightly with a cold chisel into the slot of the screw to prevent disassembling. The bottom of the counterbore is 0.125 inch, plus 0.02, minus 0.00 from the rear face of the body. This counterbore receives the head of the collar-catch screw and also forms a groove in the stem which provides clearance for drilling and tapping.

The width of the thread for the container is 0.41 inch, plus 0.01, minus 0.00. A 45-degree bevel (0.03 inch, plus 0.02, minus 0.00 wide) is required on the corner of this thread to facilitate

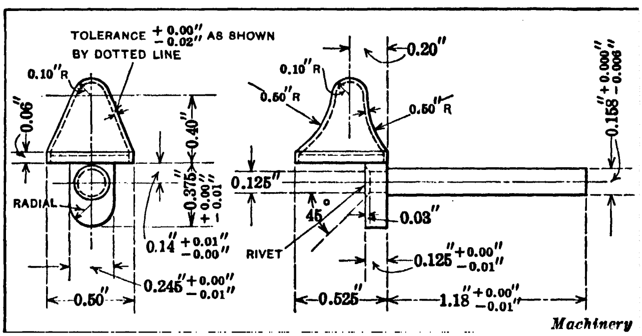


Fig. 12. Collar-catch

the insertion of the container. This bevel may be made with a file; the tolerance should be great enough to cover this method of manufacture. The ends of the thread sector are located from the 45-degree center line of the housing (see end view) at 0.02 inch, plus 0.02, minus 0.00. This sector is at an angle so as to always insure a minimum contact on this thread of 135 degrees. No tolerances are given on the various angles and radii, as none is required.

Drawing of Hinged Collar. The hinged collars and housings are not interchangeable and must be furnished in pairs. To make these parts interchangeable and insure that the housing would be screwed tightly against the shoulder on the hinged collar when the locking holes in each part were in correct align-

ment, would require very expensive manufacturing methods. In such a case, the position of the start of the Whitworth thread in the housing would have to be held very closely in relation to the position of the locking hole. The same would be true on the hinged collar. Some variation must of necessity be allowed. This would introduce a further variation longitudinally of the position of the firing mechanism. The effect of such a variation would be an additional angular variation in the locked position of the mechanism. If the original pairs of housings and hinged collars become separated, an additional locking hole will have to be drilled in the flange of the collar, Fig. 11, transferring it from the housing which is to be used. The diameter of the locking hole is 0.160 inch, plus 0.006, minus 0.000. It should be drilled in one operation by using its companion housing as a jig.

Drawing of Collar-catch. For convenience of manufacture, the collar-catch (see Fig. 12) is made in two parts which are permanently assembled. The stem and the finger piece may be made interchangeable, or a system of selective assembly may be employed. This is matter to be determined by the manufacturer to suit his own convenience. Therefore no tolerances will be given on the dimensions of the riveted end. The stem must be a snug fit in the finger piece, and the two parts must be solid after riveting. Any parts made within 0.01 inch of the nominal dimensions and which meet the above conditions will be acceptable. The rear face of the finger piece will be finished after riveting.

As the diameter of the stem is 0.158 inch, plus 0.000, minus 0.006, it should be possible to secure drill rod well within these limits; no further machining will be required on this surface. The length of the stem is of minor importance. The surface left by the cutting-off tool will be satisfactory. The length of the finger piece (0.525 inch) is an atmospheric fit; no tolerances are given, because the note in regard to the profile gives a tolerance of minus 0.04 inch.

The thickness of the flange (0.125 inch plus 0.00, minus 0.01) is of minor importance; hence the flange can be completed in a single operation after the stem is riveted. The width of the

flange (0.245 inch, plus 0.00, minus 0.01) must be free in the slot in the housing. The minimum clearance is 0.005 inch and the maximum clearance, 0.035 inch.

The dimensions of the profile of the finger piece are given without tolerances, but a note is added: "Tolerance plus 0.00, minus 0.02, as shown by dotted line." The entire upper part of the finger piece is an atmospheric fit. It must be reasonably smooth because the finger operates this part. The note permits a minus variation of 0.02 on this profile where no other tolerances are given. This variation is measured as normal to the profile at any point. If a clean drop-forging is secured, this

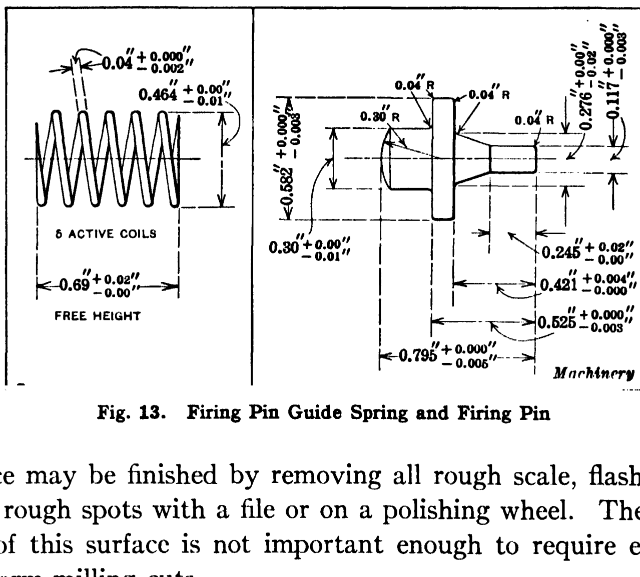


Fig. 13. Firing Pin Guide Spring and Firing Pin

surface may be finished by removing all rough scale, flash, and other rough spots with a file or on a polishing wheel. The contour of this surface is not important enough to require expensive form-milling cuts.

Drawing of Firing-pin Guide Spring and Firing Pin. The diameter of the wire for the firing-pin guide spring (Fig. 13) is 0.04 inch, plus 0.000, minus 0.002; the outside diameter of the coils, 0.464 inch, plus 0.00, minus 0.01; and the free height, 0.69 inch, plus 0.02, minus 0.00. These limits should be readily maintained under normal manufacturing conditions.

The firing-pin flange is 0.582 inch in diameter, plus 0.000, minus 0.003. This surface must be a free sliding fit in the

firing-pin guide. The surface will require a careful finishing cut. The diameter of the front end (0.117 inch, plus 0.000, minus 0.003) must be a free sliding fit in the firing pin guide. This surface requires a careful finishing cut.

The surface of the rear end clears the hole in the container by 0.050 inch and requires no finishing cut. The diameter of the large end of the taper is an unimportant clearance surface. The taper is provided to strengthen the end of the firing pin. No finishing cut is required on this tapered surface. The length over all is an important functional dimension and, in part,

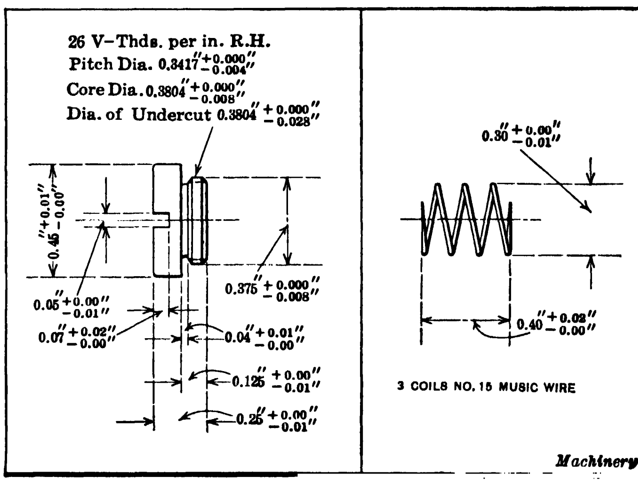


Fig. 14. Collar-catch Screw and Spring

controls the force of the blow on the primer. The front face of the pin must be as smooth as possible, and a polished surface is desirable. The rear face should be as smooth as a careful finishing cut will leave it.

The location of the rear face of the flange (0.525 inch, plus 0.000, minus 0.003) is important, as this dimension controls the location of the end of the firing pin. The surface should receive a finishing cut. The distance to the front face of the flange is an important functional dimension which controls the protrusion of the firing pin, as noted in connection with the firing-pin guide. A finishing cut is required on this surface. The

location of the beginning of the taper is relatively unimportant. This dimension maintains clearance with the bottom of the counterbore in the firing-pin guide.

No tolerances are given for the radii because none are needed. Attention is called, however, to the radius of 0.04 inch at the front end. This must not be exceeded. The purpose of this radius is to remove the sharp corner, but care must be taken to remove as little material as possible.

Drawing of Collar-catch Screw and Spring. The collar-catch screw is shown in Fig. 14. The diameter of the head must enter the counterbore in the housing. The thread, which is a sharp V-form, must assemble into the tapped hole in the housing. Sufficient threads must be secured to hold the screw in position. It is permissible to bevel both under-cut and end to facilitate threading. This screw should be completed in a single operation on a screw machine.

No. 15 music wire is specified for the collar-catch spring. Commercial wire of this number will be satisfactory. The function of this spring is to hold the collar catch in its locked position. The limits given should be maintained readily under normal manufacturing conditions.

All dimensions and tolerances given on these drawings represent limit gage sizes. If a hole is given as 1.25 inches, plus 0.01, minus 0.00, this means that the hole must be made so that a plug gage 1.25 inches in diameter will always enter, while a plug gage 1.26 inches in diameter will not. In general, the extent of the tolerances allowed on any surface is a good index of the character of the finish required. All burrs, fins, etc., and unnecessary sharp corners must be removed. All cuts and surfaces, whether rough or finished, must show no evidence of carelessness. All cuts must be made with clean and sharp tools. Gouges, tears, and unnecessary scratches produced by dull or improper tools and careless workmanship or carelsss handling should be sufficient cause for rejection.

Unless noted otherwise, common manufacturing practices, such as under-cutting and beveling for threads, extending the tap drill a reasonable amount below the threads in tapped holes,

countersinking to guide the tap, providing reasonable grinding clearances where necessary, burr-beveling corners on screw machine parts, etc., are permissible. Whenever any differences exist between the dimensions and tolerances expressed on the drawing and the above specifications, the figures on the drawing should be used. The dimensions and tolerances given on the component drawings should be strictly maintained. If modifications are possible which will relieve the situation, they should be made. No deviations from the specified requirements are permissible, however, until definite modifications are authorized.

CHAPTER VII

ECONOMICAL PRODUCTION

WHEN certain manufacturing methods are to be decided upon, the decision made in this connection should be recorded, together with the reasons for it. This practice tends to eliminate many expensive, unnecessary refinements which are often arbitrarily specified, because, instead of baldly specifying the various requirements, the necessity for adding sufficient reasons therefor demands a careful analysis of the mechanism and its purpose; and a careful analysis of almost any mechanism will soon make it apparent that only a small proportion of the dimensions and other requirements are exacting. This and many other subjects bearing upon the attainment of economical practice in interchangeable manufacturing are dealt with in the present chapter.

Principal Elements in Economical Production. There are three principal elements in the economical and successful production of a commodity. Stated briefly, they are as follows: (1) A thorough knowledge of the object (function) of the article and of all the conditions essential in attaining it. (2) The development of manufacturing methods and facilities that will most economically produce a satisfactory product. (3) The development of testing methods and apparatus to determine in an economical manner, at any stage, whether or not the desired results are being achieved.

Duplication of work never results in economy. Therefore, a record should be made of any solution reached in regard to these questions. Almost every problem has more than one satisfactory method of solution. The multiplication of solutions, however, particularly in manufacturing, is a hindrance to team work. For example, if the foreman of one department uses one solution of a problem, while the foreman of another department who performs succeeding operations on the same or

companion parts arrives independently at another solution and uses it, the final results may be chaos; whereas, if each solution is recorded, whenever or wherever made, an opportunity is created to check these solutions against each other, thus making possible the elimination of inconsistencies at an early stage of the work. This practice will aid greatly in promoting team-work, and thereby eliminate many misunderstandings.

Specifications. Specifications, in their broadest sense, include the solutions of all the three problems mentioned. This information may be compiled and recorded in one place or it may be scattered throughout the plant. In general, if the entire control of the design and manufacture of a commodity is held in one plant, the compiling and assembling of much of this information may be of doubtful value. As long as it is on record somewhere and available when needed, that is sufficient. On the other hand, if the control of the design rests with one organization, the control of the production with another, while the control of the final inspection is distinct from either of the two foregoing establishments, reasonably complete specifications are imperative if economical and expeditious production is to be obtained.

Specifications thus defined include component drawings. For purposes of discussion, however, component drawings and specifications will be considered as distinct. In this case the specifications are supplementary to the component drawings and include all information which is not given on these drawings.

Function and Essential Requirements of Product. The component drawings consist of pictures of the parts, statements of the physical dimensions required, and usually specifications of the material to be employed. By themselves they only partially solve the first of the major problems noted previously. They tell little or nothing of the object of the commodity. They state requirements, but give no reasons therefor. Thus, the first function of the specifications is to state briefly the purpose of the mechanism and its functional requirements. The preceding chapter, "Practice in Making Component Drawings," indicates the lines which specifications should follow.

A second function of the specifications is to indicate the quality of workmanship desired. The extent of the tolerances given on the drawings indicates, to a certain degree, the proper character of the finished surfaces. The specifications should supplement this information by stating not only desired results, but also reasons therefor. The preceding chapter previously referred to illustrates this practice. To a certain extent, perhaps, many of the conditions discussed there are so obvious as to need no mention, yet no harm is done by being explicit.

Another subject to be included in the specifications is the matter of the materials to be employed, and their nature, composition, and ultimate use. When standardized material is used, this can be called for directly on the component drawing, together with the proper heat-treatment. It is of interest to note that the Society of Automotive Engineers has done much valuable work in establishing standard specifications and methods of heat-treatment for nearly every kind of material used in automobile construction. The adoption of such standards greatly simplifies the provision of proper component drawings and specifications. In those cases where standardized material cannot be used, the specifications should give all pertinent information to enable the proper material to be secured. For preservative finishes the drawings or specifications should give complete information as to nature, need, and use.

When the component drawings have been completed and the specifications have reached this stage, the first important elements of the work are established. Until this is accomplished, those responsible for the manufacturing design have not done all in their power to secure the economical production of duplicate mechanisms in large quantities. Undoubtedly, many minor revisions will be required before the proper solutions of the succeeding problems will be found. But without the foregoing information, such revisions cannot be made intelligently. Furthermore, this information, in most cases, will point the way to a simple and direct solution of the succeeding problems. "Well begun is half done" was never nearer the truth than in connection with interchangeable manufacturing.

Specific Manufacturing Data. We will now consider the solution of the second major problem — the development of suitable manufacturing methods and facilities. The first step to be taken is to make up the operation lists for every component, noting in detail the type of machine, fixture, and tool required. It is of great assistance in many cases to develop concurrently the operation drawings, indicating on them the work to be performed at each operation. In addition, it is a good plan to include in this part of the work an estimate of the production time on each operation. This information is necessary to establish the amount of equipment required and also to make a comparison, when desired, of the economy of several methods.

This information should be revised and kept up-to-date after production is under way. This furnishes valuable data for estimating on new commodities and facilitates comparison between the costs of different methods of manufacturing. Such information is invaluable when it becomes necessary to call on outside plants to assist in obtaining greater production. It need not be bound together with other parts of the specifications, but it should be in such shape that it can be quickly found and readily applied. The foregoing information serves as the basis for designing the special manufacturing equipment necessary as well as for arranging the manufacturing departments so that the component parts can be produced rapidly and efficiently.

This second problem is seldom or never fully solved. Improved methods are being devised constantly, and these introduce new factors into old problems. Even greater care must be exercised in adopting a new method on work already in process of production than is required in adopting the original methods, because in these cases, ultimate economy requires that such changes result in a saving which will pay for the discarded equipment as well as for the new. The effect of a possible interruption in production must also be carefully considered.

The production records of the manufacturing equipment should be so kept that it will be always possible to trace back

through every change in equipment and make direct comparisons between the results obtained by each method. At the same time, these records should be so simple as not to entail unnecessary clerical expense. Whenever a change is made, the reason for making it should be on record. All these data furnish information which cannot be secured in any other way. As a matter of fact, many plants keep a complete record of changes, but do not provide this class of information when the production of an entirely new mechanism is undertaken.

General Manufacturing Data. In addition to the specific information required for each individual part and each assembled mechanism, there is a vast amount of general data which must be had before decisions as to the economy of different methods of manufacture can be made with certainty. Much of this information should be available from the cost department records, but, in most cases, these records are kept merely for accounting purposes and their use as engineering data often gives incorrect results.

Factory Cost of Production. It is not the purpose to outline here a new system of cost-accounting. A discussion of some of the factors entering into the factory costs of production, however, is necessary to indicate the character of the information needed to promote economical production. For the purpose of simpler accounting, it is often customary to prorate the entire amount of indirect or overhead charges against the total output of the plant, distributing them according to the direct labor costs. From the accountant's viewpoint, this method is correct. If the product of the plant consists of one simple specialized article, such a method of accounting undoubtedly gives sufficient data for general engineering purposes. On the other hand, if the products are varied, or if the productive operations are subdivided into elementary operations, performed in various departments, the data so collected are incomplete and misleading for engineering purposes, because the direct labor cost alone will be the determining factor in selecting the apparent economical methods of production. As a matter of fact, this direct labor cost is but a small percentage of the total cost of

production. It seldom amounts to 25 per cent. Furthermore, as the volume of business increases, the percentage of direct labor charges decreases. Thus, as the quantity of production increases, the data so obtained become more and more unreliable.

Another method of distributing the indirect expense consists in establishing overhead rates for each department, prorating these charges in proportion to the direct labor cost as before. If the departments are arranged to contain only one type of equipment, and to perform similar operations, the data so obtained are valuable, but such an arrangement of machines and operations is seldom possible or desirable. Different types of work creep into a department. When this condition exists, the information obtained from the use of a departmental overhead will again lead to false conclusions. Such a condition will cause manufacturing methods that are not economical to be accepted.

Certain types of equipment are always duplicated to some extent in several departments. All other things being equal, the cost of duplicate operations on duplicate equipment is identical regardless of the physical location in the plant. But with the use of departmental overhead charges, the book costs will show otherwise. For example, in one plant a sheet-metal part required a foot-press operation between two power-press operations. Foot presses were available in two departments: the power-press department with an overhead charge of 150 per cent, and a sub-assembly department in a distant part of the factory with an overhead charge of only 50 per cent. The original operation list assigned all three operations to the power-press department to eliminate unnecessary trucking and transfer. This was changed so that the second operation would be performed in the other department because of the lower overhead there. Actually, this last method cost more than the first because of the trucking and transfers back and forth, but because the book records showed a higher cost for the first method, it was disapproved despite all arguments. This is not an extreme case. Similar conditions exist in the majority of manufacturing plants.

It is realized that book costs and actual costs are not identical. To obtain such accuracy would entail a system so complex and elaborate that its cost alone would overbalance all other expenses. Yet some simple way must be found to give more nearly true costs of production in order to promote true economy of manufacture. The direct labor and direct material costs are readily obtained. Most accounting methods apply these charges directly against the individual parts, which is the proper distribution. But this, in most cases, disposes of less than half of the total cost of production. Indirect expenses are not only the most difficult to distribute equally, but also involve the larger amount of the costs. The total amount of these charges can be easily determined. This is purely a matter of bookkeeping. Their equitable distribution, however, is more an engineering than an accounting problem.

Distribution of Indirect Factory Expenses. There are three main factors to which most of these indirect expenses can be logically applied: First, the direct labor; second, the general productive equipment; third, the component parts themselves. There are also a number of other indirect expenses which must be charged to the general factory expense. As these are relatively few, they can be arbitrarily distributed over the entire product without affecting the value of the data sought. Eventually, of course, the product must carry them all. The great problem is to distribute them simply and properly.

If the attempt is made to apply all indirect charges to any one of the above factors, many economic errors will result. Attempts have been made to carry them all on the direct labor factor with far from satisfactory results. Neither can they all be applied to the equipment factor with any better results. Each factor must bear only its own indirect expenses. In order to determine where each indirect expense belongs, a process of elimination should be adopted. Without such a factor, would this expense exist? If the expense remains after direct labor, general productive equipment, and individual components are eliminated, it belongs to the general factory expenses or factory management.

Expenses Due to Direct Labor. Let us first consider the indirect expenses due to direct labor. Hereafter, for the sake of brevity, direct labor will be referred to as labor.

Cost of Supervision. One charge against labor is the cost of supervision as represented by the salary of the foremen and their assistants. The number of these depends chiefly on the number of men to be controlled. This charge could be prorated against the number of men employed. Such a method might, in extreme cases, be erroneous because the higher-priced men should require less supervision. Although, in such cases, it might be more logical to proportion this charge in an inverse ratio to the wages of the men, the clerical work necessary to accomplish this would cost more than the information would be worth.

Making up Payroll. The cost of time-keeping and making up the payroll logically belongs to the labor factor. Eliminate labor and there is no payroll to make up. This should also be distributed on the basis of the number of men employed, as it costs as much to make up the pay account of a man getting fifteen dollars a week as it does to make up the pay account of a man getting thirty dollars. Here again, the indirect expense of high-priced labor is proportionately less than that of lower-priced labor.

Employment Department. The cost of the employment department also belongs to the labor factor. Eliminate labor and there is no further need of an employment bureau. These charges should also be distributed on the basis of the number of men employed, for it costs as much to hire one man as another. In many cases the higher-priced men are the most reliable — not always, of course, as so many other conditions enter into this — and thus it is possible that a closer result would be obtained by distributing the cost in an inverse proportion to the wages of the men.

Educational Department. Wherever personnel or educational departments are established or other similar departments the objects of which are to promote cooperation between the employer and employe to their mutual advantage, all expense

incurred should be charged against labor. It is extremely difficult to analyze such charges accurately — so much depends upon the nature of the activities of such departments and upon the character of the persons with whom they deal. Therefore it might be best to distribute these charges also on the basis of the number of men employed so as to simplify the accounting by prorating all labor charges in a uniform manner.

Maintaining Health and Safety of Employes. All charges for installing safety devices, fire escapes, improved sanitary equipment, for heating and lighting, and other similar expenses necessary for maintaining the health and safety of the employes as required by law or promoted by the dictates of humanity, belong to the labor factor. However, some of these expenses might be included in other general items — fire escapes may be included in the cost of the buildings, for example — and it may not be possible or feasible to isolate them. Those few cases where it is not practicable to apply expenses directly where they logically belong will not affect the values of the final data much.

It should offer no great accounting difficulties to isolate the majority of the expenses enumerated and all other kindred items. This is all that the accountant would necessarily do. The total amount so determined could be prorated on the basis of the average number of men engaged in actual production, and thus give the labor overhead. This would be used as a constant for a predetermined period in a similar manner to the usual overhead charges, and would be close enough for all practical purposes. Of course, it is evident that this labor overhead fluctuates constantly, but as these data are for the use of engineers and not accountants, an exact balance is not essential. As a matter of fact, the use of a general overhead burden does not give an exact balance. A comparison between estimated results and the accountants' records will show how wise a use has been made of this information. This direct labor overhead is a valuable factor in determining economical methods of production. If the general type of labor employed differed to any great extent in the various departments, a separate labor overhead could be established for each department.

Machine-hour Rate. Next will be considered the indirect charges that belong to the general productive equipment which, prorated on an hourly basis, will be called the machine-hour rate.

Interest on Investment, Depreciation and Insurance. The first items are the interest on the investment, depreciation, and insurance. These are relatively simple to determine. Their maintenance charges belong here also. When possible, these should be applied to the particular types of machines. The many petty items would be distributed over the entire equipment. Having the machinery, there must be a place to put it. The majority of the factory space is utilized by productive equipment. It would seem, therefore, that all the fixed plant charges would be best distributed here. This could be done proportionately to the average floor space required for operating each type of machine.

Power Charges. The power charges would also be included in the machine-hour rate. One cannot go into the exact distribution of this factor without incurring great expense in power tests — tests that become valueless as the machining cuts vary from light to heavy, short to long. An approximation could be made which would determine the value of this factor close enough for practical purposes. A few power tests could be made to advantage for the purpose of securing data to assist in the proper distribution of all power costs. The cost of belting and lubricating oils, etc., could also be included in the total power charges. Such a plan would insure an equitable and simple method of distributing these.

Non-productive Time of Machines. There is always a certain amount of idle time for any machine, no matter how well the work is planned. The amount of this normal non-productive time varies for different types of machines. For example, an automatic screw machine — as efficient a productive machine as there is — is idle on an average of one hour in five. This idle time is caused by the necessity of adjusting tools, oiling, changing bars, etc. Therefore, the actual productive time of this machine is 80 per cent of its total operating time. In the printing trades, where a complete system of machine-hour costs has

been developed, 65 per cent is considered as a normal average of productive time. The normal percentage of non-productive time should be estimated as closely as possible and included in the machine-hour rate.

Lack of Work or of Labor. There is, however, another source of idle time to be considered. This may be lack of work or lack of labor. If it is lack of labor, it should logically be charged against the employment department. Lack of work may, of course, be due to one of several causes. If due to lack of business, it could be charged against the sales department, while if due to poor planning, it belongs to the general factory expense. For simpler accounting, abnormal idle time might best be included in the general factory expense.

Keeping of Records. The shop office carries records of the machinery, such as inventory lists giving the original value, depreciation, locations, etc. The results of using machine-hour rates would be, to all intents and purposes, the creation of a payroll for the various machines. All this would require a certain amount of clerical work, the cost of which should be prorated against the machines.

The accountant would carry accounts showing only the total amounts spent for power, belts, lubricating oil, fixed plant charges, fixed charges on general manufacturing equipment, labor costs for machine records, etc. These totals would be prorated as just discussed to establish a constant machine-hour rate for each type of equipment, which would be simple to apply. Such values would be adjusted periodically as required. Here, again, the successive reports of the accountant would make apparent how wise a use had been made of the information so gathered.

The mechanical manufacturing industries would find it well worth their while to follow, in one respect at least, the example of the printing trades. The problem of the actual cost of production has been studied by them on a cooperative basis. For several years, one of their trade journals has been collecting cost data from many plants throughout the country. The information so willingly given has been compiled and analyzed for the

benefit of all. As a result, a complete series of average machine-hour costs has been developed, the use of which gives results very close to the actual balances of the accountants. This data is kept up to date and corrected values are distributed periodically. This information is invaluable for estimating and other planning purposes.

Product Overhead. The indirect expenses due to the product itself will now be considered. The following method of distributing indirect costs is a radical departure from any established practice, yet their logical distribution leaves no other path open. There are two classes of these charges; those which can be applied to specific component parts and those which apply to the whole product in general. For the sake of brevity, those of the first type may be called specific product charges and those of the second, general product charges.

Specific Product Charges. The most important specific product charge and the one most readily isolated is that for jigs, fixtures, special tools, and gages. These certainly belong to specific parts. The adoption of this practice will soon develop a valuable record. It will then be possible to obtain — and apply directly where it belongs — the cost of making changes in the design and methods of manufacturing of the various parts. Then only will it be possible to determine whether or not such changes result in an economic gain. The writer believes that frequent changes of this sort are altogether too common in American manufacturing practice. Judging from personal experience during the past ten years, the majority of such changes are the results of mental laziness. When the first important difficulty appears, the issue is avoided instead of being carried through to its logical conclusion. It is the easiest thing in the world to try to make a part in a different way from the one originally planned; but by so doing one set of difficulties with which we are somewhat familiar is merely substituted by others with which we have had no previous experience, and, in the end, no progress has been made. The writer feels safe in stating that not less than seventy-five per cent of the changes made are attempts to avoid trouble which is not eventually escaped,

and that this percentage of the cost of changes represents a total economic loss. A method of distributing indirect expenses along the lines indicated will expose such conditions as nothing else will.

Another specific product charge is the cost of constructing special machines for specific parts. This is logically included in the jig and fixture costs. When the special machine is used on several parts, these expenses, of course, will be classified with other general machinery items. Its normal non-productive time, however, is usually large.

The loss resulting from scrapped work is another specific product charge. Some parts are delicate and difficult to machine and this results in a high percentage of scrap. Others are simple and more rapidly produced with little or no scrap. It is manifestly unfair to distribute this item of expense over the product as a whole because this will give an entirely wrong idea in regard to the economy of the simpler and sturdier designs. Often, when the design is changed, a large number of finished parts are scrapped or reworked. All such expenses should be charged to specific pieces when possible. There will, of course, be some credit items, due to salvage. If it should be difficult and expensive to distribute these salvage credits specifically, they could be credited to a general scrap account and applied proportionately to the cost of the scrap charged against each part. Any inaccuracy resulting from this procedure would have little effect on the value of the final result.

General Product Charges. Most of the other expenses incurred by the product are general product charges. Among them would be the cost of trucking, including the interest on the investment of the trucks, elevators, etc., depreciation, and their maintenance costs. The expenses of shop rearrangements also belong with the general product charges, as these alterations are made to facilitate production. If, however, they can be charged directly to specific component parts, they should be so distributed. The majority of the factory office expenses would be included in the general product charges. This would include the cost-keeping, production records, engineering and

experimental work, etc. All these general product charges could be distributed in conjunction with the general factory expenses. This method would be as equitable as any.

Clerical and Accounting Work. The clerical and accounting work which such a procedure would entail will now be considered. First, the accountant must arrange his books so as to separate all expenses due to direct labor. This would be only a single account. Next he would open another account to carry all the expenses making up the machine-hour rate of the general productive equipment. Another account would be opened for the indirect charges due to the product. The indirect charges caused by the purchase and handling of the material have not been previously mentioned. These would be handled in the same manner as the other indirect expenses, and distributed over the direct material. The accountant would carry this account, and one to cover the general factory expenses which are not distributed elsewhere. These would be all of the indirect factory expense accounts which he would require. He would also carry direct labor and material accounts. The sum of these accounts would represent the factory cost of production of the work produced during a given period. This, balanced against the value of the output would represent the gain or loss during the specified period. This is the essential information in which the stockholders and directors of a plant are interested.

The factory cost department would carry independent accounts along entirely different lines. These should give detailed information in regard to the cost of each component. They need not necessarily check exactly with the accountant's records. The constants which are used by the factory should be so established as to make the total of these records a small percentage higher than the accountant's. A factor of safety of, say, 5 per cent, should be included in the various constants. The direct labor and material charges are the only ones which should check absolutely in both sets of records, while all the others need check only within the limits of the factor of safety established. The various constants would, necessarily, be adjusted from time to time to bring this result.

The factory cost department would carry an account for each separate component, including sub-assemblies and complete mechanisms. Records must be kept on each of these accounts, showing the direct labor, direct material, machine-hours, special equipment, and scrap charges. To this would be added the proper direct labor overhead, direct material overhead, machine-hour rates, general product overheads and general factory expense. These last would be specified constants. The comparison of these shop records with the accountants' records would prove, first, the relative accuracy of the established constants, and, second, how effective a use had been made of the data that was so collected.

If it were possible for several manufacturing concerns to adopt a method of factory cost-keeping along these lines and to compare from time to time, not the details but certain of the resultant factors, much valuable information would be secured — information which would not in the least reveal any of the confidential facts of the business but would uncover many economic truths as yet undiscovered. For example, it is of the utmost value to determine what the normal direct labor burden should be. The different plants involved in such an undertaking need not be engaged in the manufacture of the same products, and their methods of manufacturing might differ in many particulars, yet from data so obtained the normal cost of this factor could be determined closely. These plants would thus establish a standard with which to compare their costs, giving them either the gratifying knowledge that their labor burden was normal or else a warning of conditions that should be corrected. The same is true in regard to the machine-hour rates. With cooperation between a large number of plants, an accurate series of values could be established for these rates. Accuracy or precision in manufacturing requires established standards. Why should not the same principle be applied to other problems? If relative standards for machine-hour rates and direct labor overhead are established, for example, the same progress can be expected in these respects as has been made in mechanical work since the establishment of physical standards. It may

be a long and slow process, but there is sure to be improvement during its development. The product factors would be of little value for general comparisons. Their nature prevents their economic use for this purpose.

Inspection and Testing. The third major problem — the development of inspection methods and facilities — should be solved to a great extent in conjunction with the development of the other manufacturing equipment. The inspection operations and necessary gages should appear in their proper place on the operation lists. In some cases, these lists should be supplemented by a more detailed description of the methods of inspection. This is unnecessary for limit gages measuring elementary surfaces. It is required, however, in connection with the use of functional and other gages for many composite surfaces. Such information should be included in the specifications as an integral part of the description and requirements of each component part.

Specific and General Information. It is obvious, then, that specifications may be divided into two main divisions. The first division contains the specific information required in the production of particular commodities. The preceding chapter gives a good illustration, as far as the requirements of dimensions and surfaces are concerned, of the nature of specifications of this class. Operation lists, material specifications, inspection requirements, etc., are needed to make them complete. In this way, the efforts of all will be directed along similar lines, the exacting requirements will receive the greatest attention — and this they should always receive — while those of lesser importance will be treated accordingly.

The second division consists of that vast amount of general information that is derived from cost and production records, "traditions of the shop," and all other general data gleaned from every possible source which applies equally to every commodity. This should not be duplicated in the written specifications of every individual commodity, but should be gathered independently in usable form.

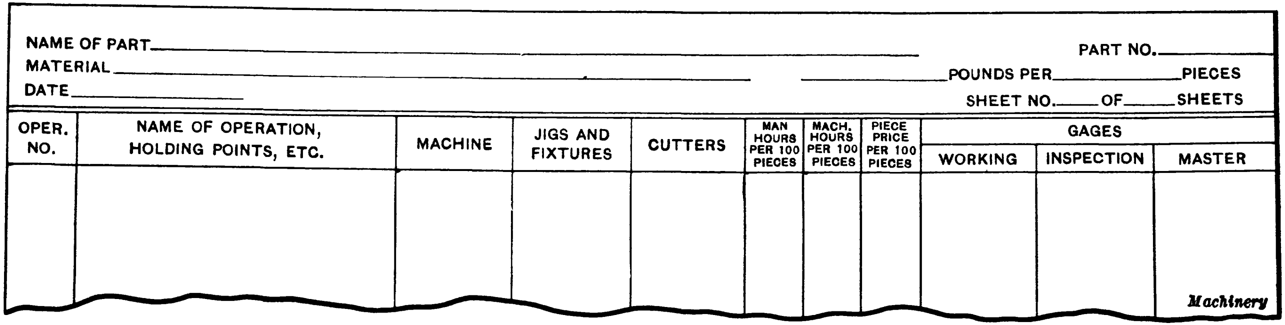
CHAPTER VIII

EQUIPMENT FOR INTERCHANGEABLE MANUFACTURING

In the preceding chapters an idea was given of the information required for interchangeable manufacturing, desirable lines to be followed in obtaining these data were indicated and proper methods of recording this information were described and illustrated. Even with the exercise of the greatest care in this preliminary work, many petty details will be overlooked; but the design and construction of the manufacturing equipment can be carried through with expedition and confidence as soon as this preliminary information is obtained. If time is important, the work of designing and constructing this equipment can be turned over to a large number of persons or to several different plants to develop independently. It is, of course, essential that a uniform method of interpreting drawings and tolerances be used, and that complete operation lists be furnished.

These operation lists should map out the plan of action for the selection or design of the equipment. Fig. 1 shows a form which has proved satisfactory in service. The preliminary lists should give such descriptions of the special tools and gages to be made that their design can be readily developed. The final lists may refer to these tools and gages by number only. If these lists are kept up to date, they become a valuable key to all production.

Selection of Machine Tools. In order to insure ultimate economy, the proper choice must be made between standard or special machine tools. The amount and type of available equipment affects this decision. In general, standard equipment is advisable, although occasionally the reverse is true. For example, in the case of an extremely high rate of production, special automatic machines built to serve one specific purpose prove more economical. In other cases, a small special, single-



NAME OF PART ______ PART NO. ______
MATERIAL ______ ______ POUNDS PER ______ PIECES
DATE ______ SHEET NO. ____ OF ____ SHEETS

OPER. NO.	NAME OF OPERATION, HOLDING POINTS, ETC.	MACHINE	JIGS AND FIXTURES	CUTTERS	MAN HOURS PER 100 PIECES	MACH. HOURS PER 100 PIECES	PIECE PRICE PER 100 PIECES	GAGES		
								WORKING	INSPECTION	MASTER

Fig. 1. Operation Sheets on which should be given Essential Information required in designing Special Tools and Gages

purpose machine can be built as cheaply as a special fixture to be used on a standard machine tool.

The following factors must be taken into account if ultimate economy and high quality of product are to be secured. In purchasing new equipment its first cost must be considered. This, in itself, should never be the determining factor, neither should it be entirely ignored. The operation and maintenance costs are of far more importance than the first cost. These are important whether the equipment is old or new. If general data are compiled, in the manner described in the preceding chapter, a convenient and reliable source of information will be at hand to assist in establishing the economical balance between the first cost and the operating expenses.

In the course of time new demands are made of different classes of commodities. The typewriter, for example, was originally built to handle ordinary correspondence. Now it is also used in making up invoices and loose-leaf ledger sheets. In some cases, special machines are used for this purpose, but there are firms that cannot afford a double equipment of

typewriters; hence, to meet this demand, new features have been introduced on the machines, such as tabular stops, etc. The possibility of such modifications must never be overlooked. Another characteristic of the machine tool equipment, therefore, is its adaptability. All other factors being equal, that machine which is the most adaptable to other operations should be chosen. In this connection, it is of interest to note that single-purpose machines are usually the more adaptable, and furthermore, that they often prove more economical in other

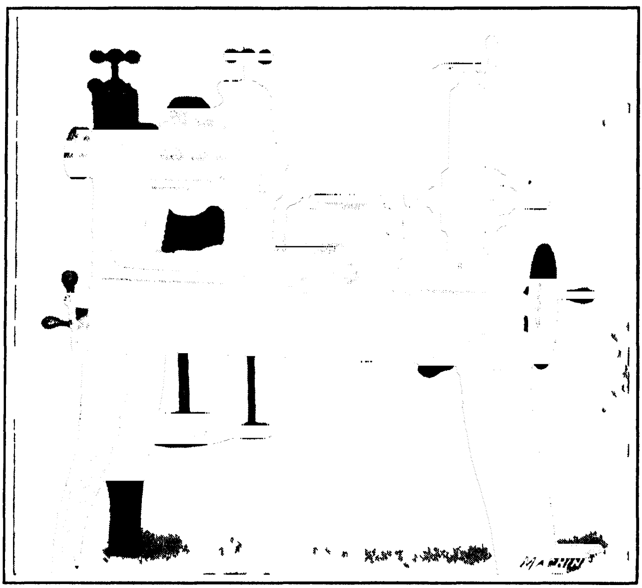


Fig. 2. Early Type of Manufacturing Milling Machine

ways. For instance, the writer knows of a watch factory which was engaged in making fuse bodies during the war. Some were made on semi-automatic turret lathes and others were machined on small bench lathes. The turret lathes practically completed the parts in two operations, while more than a dozen operations were required on the bench lathes. The parts produced on the bench lathes were not only more nearly identical than those produced on the turret lathes, but also cost less to manufacture.

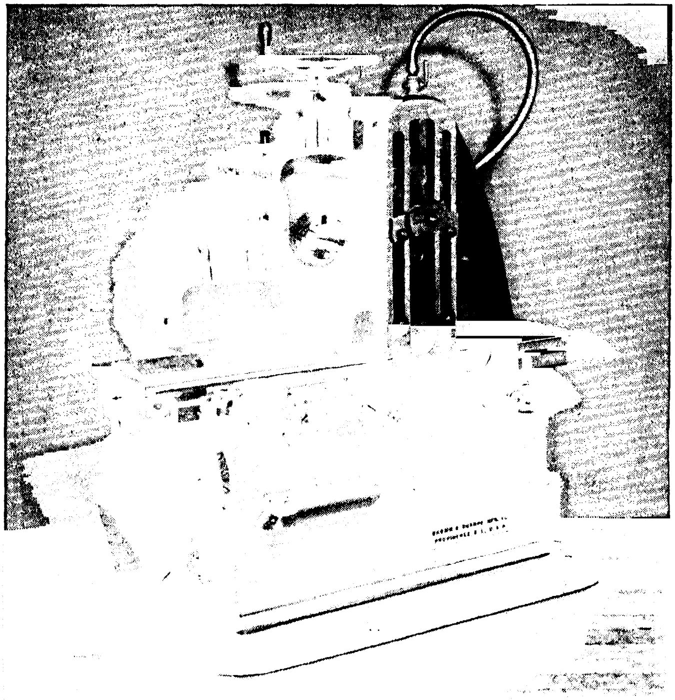


Fig. 3. Modern Type of Manufacturing Milling Machine

The turret lathes were purchased for this job while the bench lathes had been formerly used in turning watch cases.

The machines selected must be sufficiently rigid to perform their task. The introduction of high-speed cutter materials has created more severe conditions than formerly existed, and the improvement of the cutters in this respect has caused a great increase in the rigidity of many machine tools. It is interesting to compare the general construction of an earlier type of manufacturing milling machine shown in Fig. 2, with that of a modern type shown in Fig. 3.

From the production standpoint, the most important factor of the machine tool equipment is the facility with which it can be set up, adjusted, and operated. Several successive operations on simple single-purpose machines are often

more economical than a single operation on a more complicated machine. The actual production time of the latter may be much less than that of the former, but when it is stopped for adjustment and setting-up, the loss of production is correspondingly greater. Furthermore, the multiplicity of adjustable parts makes it necessary to stop for readjustments more frequently. It should not be assumed from this that single-operation machines are always the most economical, because on parts having liberal tolerances the reverse is true.

Design of Jigs and Fixtures. Jigs and fixtures are provided to assist in machining specific surfaces on specific parts, and

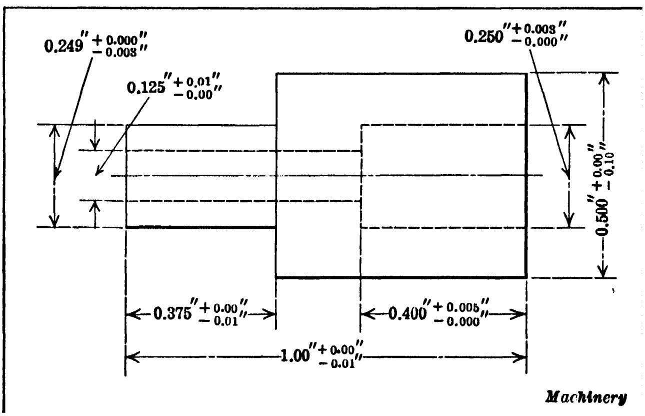


Fig. 4. Drawing of Stud machined in One Operation on a Screw Machine

their design depends to a large extent upon the design of the parts to be machined. There are, however, a number of general principles which apply equally to all types of fixtures. The holding or register points of tools and fixtures for all finishing cuts should be identical with those surfaces from which the dimensions are given on the component drawings. On roughing cuts, these holding points are of lesser importance, yet it is good practice to maintain, as far as possible, the same register points on both roughing and finishing cuts. The stud shown in Fig. 4 is presented as a simple example to illustrate this principle. It will be noted that the dimensions of length, except the

depth of the counterbore, are all given from one end, that the depth of the counterbore is given from the opposite end, and that the part is to be machined all over. This part can be machined in a single operation on a screw machine by means of the tools illustrated in Fig. 5.

Surface *Y* of the cutting-off tool *A* establishes the register point for forming tool *B* and facing tool *C*. Surface *X* of the forming tool is adjusted in relation to surface *Y* of the cutting-off tool so that the length of the stem on the work will be as given on the component drawing. Surface *Z* of the facing tool is also adjusted in relation to surface *Y* of the cutting-off tool in order

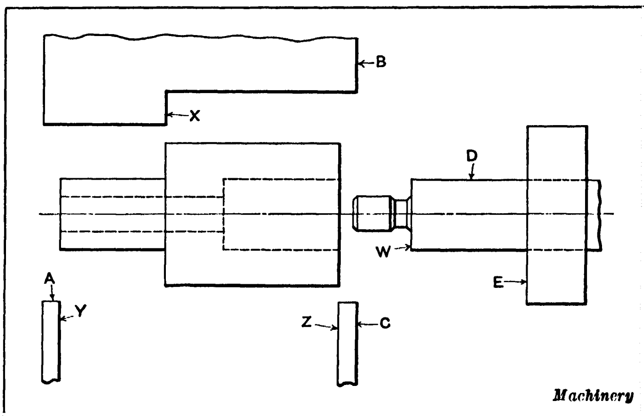


Fig. 5. Diagrammatic Illustration of Tools used in machining Stud

to maintain the proper over-all length of the piece. Counterbore *D* is provided with an adjustable stop *E* which registers against the forward end of the stud. The contact surface of this stop is adjusted in relation to surface *W* of the counterbore so as to maintain the prescribed depth.

If the bottom of this counterbore were located on the component drawing from the end of the stem, the stop on the turret would be adjusted so that surface *W* of the counterbore would keep its proper position in relation to surface *Y* of the cutting-off tool. Stops on the cross-slide carrying the forming tool control the outside diameters.

The next question that arises is the proper limit at which to set the tools. There are four main sources of variation to consider: First, the errors resulting from imperfections in the machine; second, those caused by wear on the cutting edges of the tool; third, those due to errors in the tools; and fourth, those caused by improper setting of the raw material in their holding devices. In the following, only those variations which affect the lengths of the stud will be dealt with.

Results of End Play in the Machine Spindle. Any end play in the spindle of the machine will reduce the distance between the surfaces machined by tools *A* and *C*, Fig. 5. If the forming and cutting-off tools are held rigidly together, this end play will not affect the distance between the surfaces machined by tool *A* and surface *X* on tool *B*. If, however, these two tools are independent of each other, as shown in the illustration, this end play may cause a variation in either direction. In the first case mentioned, a male dimension is dealt with and inaccuracies in the action of machine tools cause a minus variation in such a length whether the cutting tools are independent of each other, or combined in a single tool. Similarly in the case of a female dimension, it is evident that the variation will be plus. End play in the machine will not affect the depth of counterbore when the tool is self-registering as shown; thus a self-registering tool often produces more accurate results than one controlled by stops on the machine itself.

Wear on the cutting edges of tools *A* and *C* will increase the distance between surfaces *Y* and *Z*, but if the wear on surfaces *Y* and *X* is uniform, no variation will develop from this source. If it is not uniform, the variation may be in either direction. As surface *W* becomes worn, the distance between this surface and the contact surface of stop *E* decreases, that is, of course, assuming that there is no appreciable wear on the contact surface of the stop.

Considering only the first two factors, that is, imperfections in the machines and wear on the cutting edges of the tools, the original setting of facing tool *C* should be as near to the minimum limit as the accuracy of the machine permits; the setting

of forming tool *B* should be at the mean dimension until actual practice demonstrates a tendency to vary more in one direction than the other; while the setting of stop *E* on counterbore *D* should be as near to the maximum limit as possible. This will give the maximum time between readjustments. The conditions created by errors in the tools themselves will be dealt with later in this chapter.

Results of Wear on Cutting Edges of Tools. It is thus evident that the effect of imperfections in the operation of machine tools, when the cutting tools are located by stops on the machine, is to cause a plus variation on female dimensions, a minus variation on male dimensions, and a plus and minus variation on neuter dimensions, such as the horizontal distance between surfaces *Y* and *X*, which cannot be strictly classified as either male or female. In other words, imperfections in machine tools, such as end play, etc., cause additional metal to be removed. In a similar manner, the wear on the cutting edges of the tools causes a minus variation on female dimensions, a plus variation on male dimensions, and a plus or minus variation on neuter dimensions. In the last case, if the cutting edge of one tool consistently wears faster than that of the other, the variation will run in only one direction. Assuming that surface *Y* wears faster than surface *X*, the variation will be plus. If the wear is equal, no variations develop from this cause. In other words, the wear on the cutting edges of the tools usually causes a variation in the reverse direction from that caused through the presence of imperfections in the machine tools.

The same principles apply equally to all types of operations such as turning, milling, planing, grinding, profiling, shaping, boring, etc. In order to establish the proper dimensions for the holding and registering points on tools and fixtures, it is necessary to analyze each particular surface carefully and proceed accordingly.

In the above example, errors due to the improper setting of the stock in the holding device are not present. In the case of milling, drilling and other similar operations, where the parts are handled singly instead of being machined from bar stock,

this is one of the most serious problems. Chips are apt to remain on the locating points or the operator may fail at times to seat the piece properly before clamping. In the case of drilling, this results in the improper location of the holes. In the case of other operations, it will result in removing additional stock. Proper training of the operator is the only cure for this fault. Correctly designed fixtures greatly reduce the chances of these errors, yet, as in other matters, it is not possible to make everything so that it will be entirely fool-proof.

Important Factors in Designing Fixtures. The second important factor of the design of fixtures is their operation in service. The selection of the proper locating points controls in a large measure the uniformity of the product. The facility with which these fixtures may be operated determines to a great extent the rate of production. The direct labor cost of production is also greatly reduced with quick-acting jigs and fixtures. On the other hand, such equipment is often very expensive, and therefore the total output involved determines the amount of money which may be economically expended on the equipment. In the case of a very small total output, little or no special equipment need be provided.

When continuous production is involved, every effort should be made in designing the equipment to have it operate rapidly. It should operate easily and with a single motion of the operator's hand if possible. Second, the fixture should open so that the part to be removed is accessible. Third, the position of such openings in relation to the cutting tools should be such that there is no danger to the operator. Whenever the operator is required to place his hand close to the cutting tool, he normally moves slowly and cautiously, thus reducing the rate of production. Fourth, all exposed sharp corners and edges on the fixtures should be eliminated to prevent injury to the operator. Fifth, the locating points should be accessible, to facilitate cleaning and the proper insertion of the work. Sixth, liberal chip clearances should be provided to facilitate cleaning the fixture and also to prevent marring the machined surfaces of the parts under the process of manufacture.

Examples of Efficient Fixture Design. Except for relatively large parts, careful study will make apparent a simple and effective means of clamping the work with a single motion of the operating handle. Loose nuts and screws should be avoided for clamping purposes whenever possible, as these are very slow to operate. A milling fixture which requires only a single motion to clamp is shown in Fig. 6. An assembly view of this

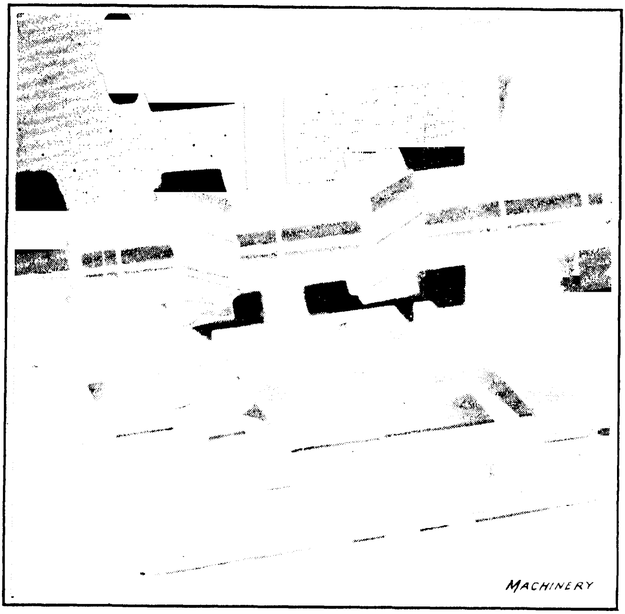


Fig. 6. Design of Milling Fixture in which Three Pieces of Work are clamped by a Single Motion

fixture is shown in Fig. 7, and the details of its construction will be understood by reference to this illustration.

This fixture is used when milling the bottom, right- and left-hand sides of a small forging in a single operation. The forging is first placed in the position indicated at *A* by dot-and-dash lines, where one side is milled. This piece is then advanced to position *B*, where the opposite side is milled. It is then inserted at *C* in which position the bottom is milled. In actual operation, when the original piece is placed in position *B*, a second

piece is placed at *A*, and when the original piece is moved to *C*, the second piece is moved to *B* and a third piece is placed at *A*. Thus three pieces are being machined at the same time. All three parts are clamped by one motion of the lever, *D* and *E* being fixed jaws and *F* and *G* clamping jaws. The cam which is attached to the operating lever draws back the jaw *F* and pushes forward the jaw *G*. The jaw *F* is designed so that it can

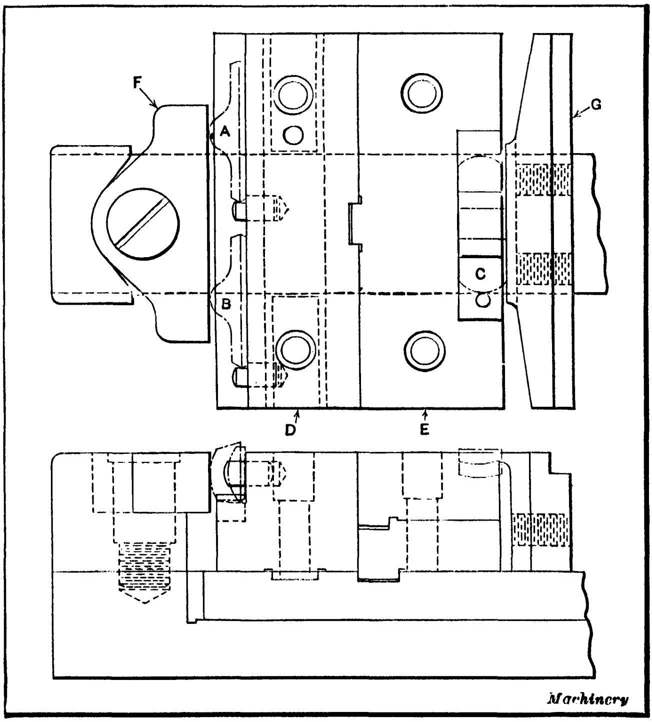


Fig. 7. Assembly Drawing of the Milling Fixture illustrated in Fig. 6

rock, thus securing the parts at *A* and *B* with equal pressure regardless of the variations in size between the two pieces. This particular construction permits clamping in three places simultaneously with a single motion of the operating lever. Modifications may be made in this design which will permit clamping in three or more different directions when this is desirable or necessary.

Inaccessibility is one of the most common faults found with jigs and fixtures. Sufficient clearance should always be allowed to enable the operator to remove the completed work readily and also to insert a new part and hold it in position while clamping. Careful attention to this point will greatly promote rapid production. Fig. 8 shows a spline milling fixture which affords a simple example of this point. The construction of this fixture is shown in Fig. 9. Two pieces are held at one time, the pieces

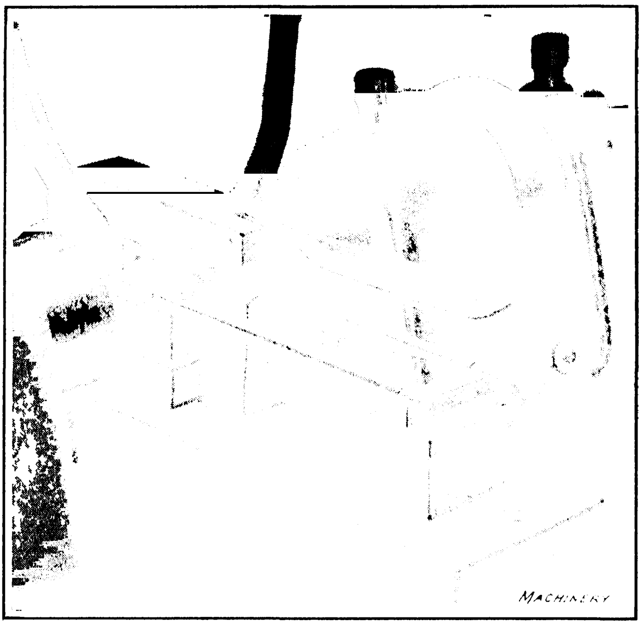


Fig. 8. Machine provided with Fixture used in Spline Milling in which the Work is Readily Accessible

being clamped in position by a leaf. It will be noted that each piece is clamped in two places by a single operating lever. The leaf is hinged so that it may be thrown back out of the way when the work is being removed or inserted. The rapidity with which this can be accomplished is a means of increasing the production.

Protection from Cutting Tools and Sharp Corners. In many cases, standard machine tools are so designed that the table is well away from the cutting tool in its loading position. In the case of

drill jigs, the operator withdraws them from beneath the spindle of the machine before he unloads them. Sometimes, however, the design of the machine tool or fixture is such that the fixture cannot be removed from under the cutting tools. In such cases, if the fixture cannot be designed to open on the side away from the cutting tool, provision should be made for rolling or rocking the fixture away from the tool. If this cannot be done, some safety device

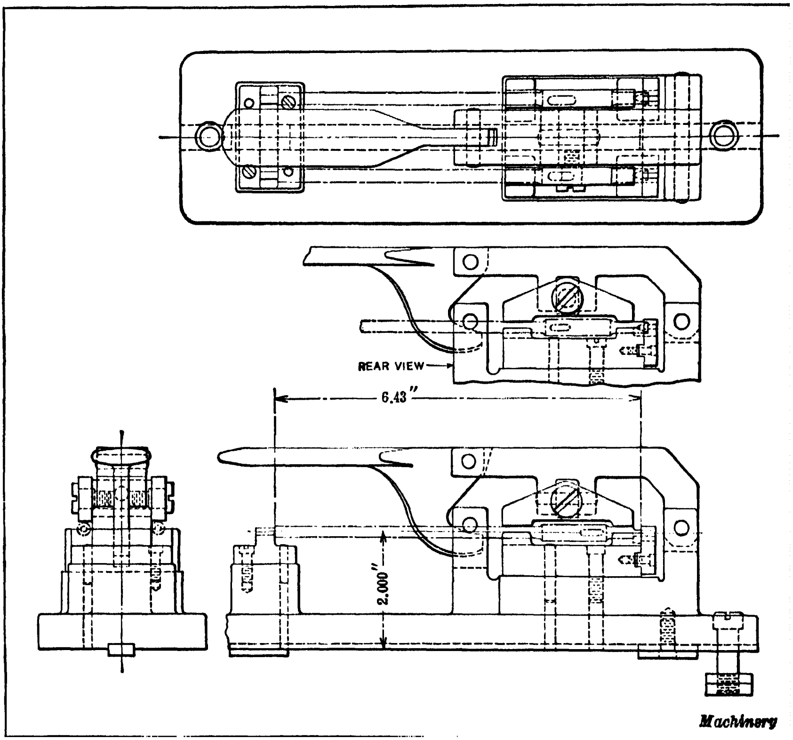


Fig. 9. Construction of Spline Milling Fixture

should be designed which will stop the cutting tool and prevent it from starting while the operator's hand is in any position of danger. Safety guards and automatic stopping devices on punch presses are good examples.

It is evident that the operator will handle a jig or fixture without sharp edges much more quickly and surely than one on which he is continually tearing his hands. It is the standard practice of

most tool-rooms to remove all such corners carefully, whether the drawing of the fixtures specifies it or not.

Accessibility of Locating Points. The locating points in the jigs and fixtures should be so placed that they can be readily reached. This not only facilitates the cleaning of the fixture but enables it to be more accurately made. It also allows any necessary corrections due to wear or change in dimensions to be quickly and economically made. These locating points should stand clear and be as nearly self-cleaning, as regards chips and dirt, as it is possible to make them.

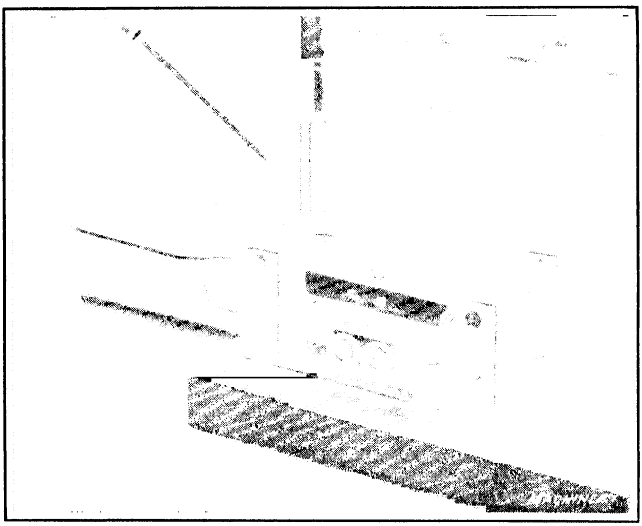


Fig. 10. Jig designed to permit Easy Removal of Chips during Various Operations on the Same Piece

Necessity for Proper Chip Clearances. Careful consideration should always be given to the provision of suitable chip clearances. If this point is neglected, the operator will often spend more time in removing the chips from the fixture than he does on any other operation. On the other hand, if he does not remove them, inaccurate work will result. Many ingenious devices have been developed for cleaning. A jet of compressed air or a stream of oil or soda water properly directed often accomplishes this task quickly and well, and this demands that

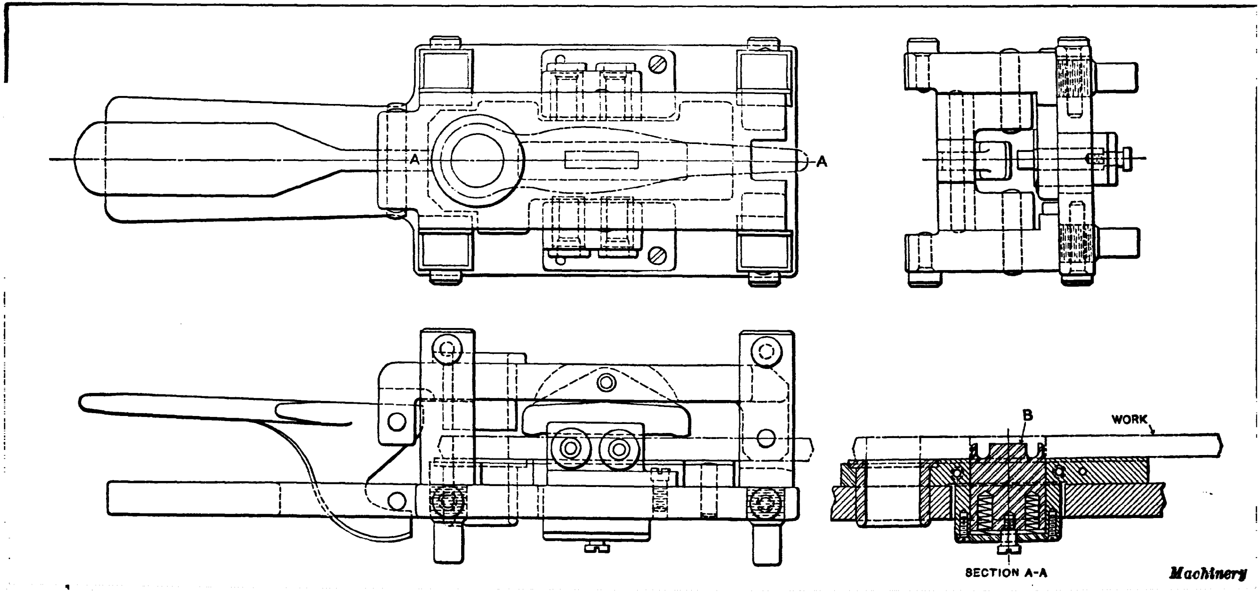


Fig. 11. Assembly Drawing of the Jig illustrated in Fig. 10

the design of the fixture be such that the chips are readily carried away. A little attention to this point by the tool designer will often save hours of time later during production — time of both operator and machine. In Fig. 10 is shown a simple jig which illustrates, among other features, simple methods of

obtaining chip clearances. The construction drawing of this fixture is shown in Fig. 11. The part to be drilled is located in one place by the tapered tongue *B* shown in section *A–A*, and is clamped by a leaf. The body of the jig is a skeleton frame which contains no pockets to catch the chips. The leaf swings open, thus allowing all chips to be easily brushed or blown out.

Results Obtained with Proper Chip Clearances. The following example shows the results actually obtained in production by attention to these details. A certain firm contracted to make 200,000 small pinions as shown in Fig. 12. It will be noted that three of the six teeth are partly removed. The

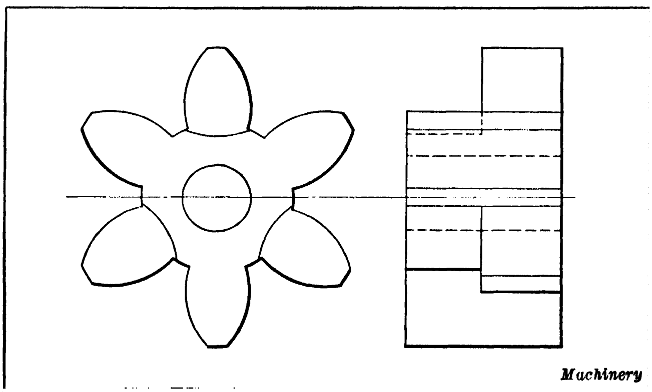


Fig. 12. Pinion having Three Teeth partially removed

pinions were made from brass pinion stock being extruded to form, after which they were drilled and cut off in an automatic screw machine, and counterbored in a drilling machine to remove the stock from three of the teeth.

The drill jig first employed in the last operation was one with a leaf in which several pinions were held. It was designed and built without much thought, as the job seemed simple and unimportant. The parts were so small and difficult to handle rapidly and the chips were so troublesome that the best rate of production possible with this jig was about 160 an hour. This was so far under the estimated production that a serious loss on the contract seemed inevitable. After a little study, a new

jig — incidentally a cheaper one than the original — was designed and built. This jig is shown in Fig. 13. A pair of parallel jaw pliers *A* was used as a basis. These had special jaws *B* inserted to hold the pinions, one of them carrying plate *C* which had three holes that served as drill bushings. Spring *D* which was attached to one jaw, opened the pliers, while the grip of the operator closed them and held the pinion in position. A cast-iron parallel *E* about two inches high was clamped to the table of the drilling machine, and two rods *F* which served

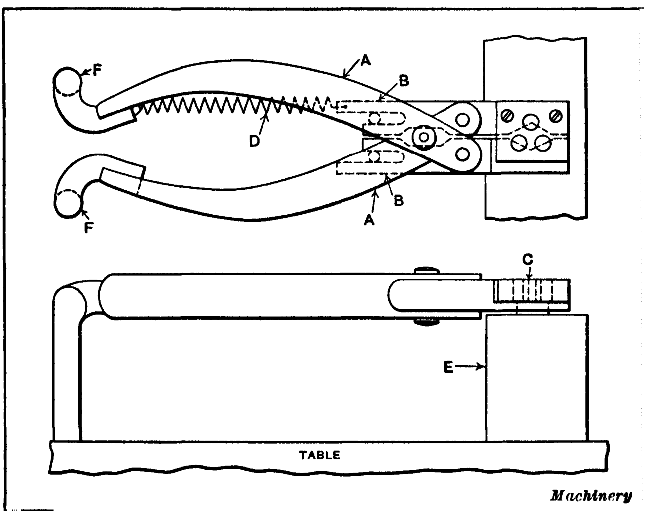


Fig. 13. Jig developed for handling Pinions in Counterboring Operation

as feet to level the device, were riveted to the handles of the pliers. The bottom of the pinion rested on the cast-iron parallel, while the top rested against the drill plate *C*.

The operator handled this jig as follows: About half a dozen pinions were placed on the cast-iron parallel approximately an inch apart. The open pliers were placed over the first piece and then closed. The shape of the jaws insured that the piece when clamped would be in the proper position for the operation. The pliers were then slid under the spindle of the drilling machine and the pinion was counterbored. To unload, the operator

moved the jaws away from the cast-iron parallel as he released his grip. The completed parts and all chips then dropped out, and he proceeded to pick up the next pinion. The rate of production with this jig was over 500 an hour, and nearly double the estimated output.

Simplicity and Standardization of Jigs and Fixtures. Needless to say, the greater the rigidity of the tools the greater the accuracy of the product. Whenever possible, the pressure of the cutting tools should be withstood by a solid part of the fixture and not by a clamp. Fixtures which are permanently fastened to the machine should be sufficiently rugged to withstand all use and abuse. Independent jigs which must be lifted or turned over in operation should be as light as they can safely be made. The design in all cases should be as simple as possible because simplicity is a primary source of economy. This simplicity, however, is seldom attained spontaneously. It is the result of constant study and careful and painstaking development. It may be safely asserted that designs which are not simple are incompletely developed.

Economy in the construction of jigs and fixtures offers a field for standardization. Not only the various drill bushings, operation levers, drill jig feet, vise jaws, etc., but also the baseplates for jigs and fixtures, various clamping devices, leaves, etc., can be standardized to advantage. This is now common practice in many up-to-date tool-rooms.

Methods Employed in Manufacturing Fixtures. The information required on fixture drawings depends to a large extent upon the methods to be employed in the construction of these fixtures. One of two general methods is usually employed. First, the complete fixture may be made by one man or a small group of men working in close cooperation. Second, the work on all fixtures may be resolved into its elements and one man or one group of men may do only the work of a certain type, such as planing, milling, boring, etc.

Each method has certain advantages and certain disadvantages. Among the disadvantages of the first method are the following: When one man performs all types of operations,

either the tool-room must be over-equipped with machinery or a considerable amount of time will be lost by the various men in waiting their turn to use certain machines. Again, few men are equally expert in operating all types of machinery. The use of this method prevents the specialization of the men on those operations in which they are most expert. In order to overcome the foregoing disadvantages, the second method has been used. This often results in reducing the amount of tool-room equipment and increasing the total output. On the other hand, the elimination of the disadvantages of the first method has resulted in the loss of many of its advantages. With the first method, the toolmaker takes a personal interest in the development and completion of a certain fixture. It is a complete mechanism in which he can take personal pride, and this advantage is lost by the adoption of the second method. Furthermore, a careful distinction must be made between working time and elapsed time. The adoption of the second method, while it often reduces the total working time required to complete tools, inevitably increases the elapsed time between the receipt of the order and the delivery of the completed fixture.

To operate successfully under the second method, a certain amount of work must be kept ahead of each operation. This means that although the machines and men may be kept busy, each piece of work must wait its turn at each operation. Thus, in many cases, the elapsed time required to complete the fixtures under the second method is more than double the elapsed time required under the first. For replacement work, which can be anticipated and started well in advance, and for new work when time is not essential, the second method is often the better. In other cases, if ultimate economy is desired, the first method must be employed. Take for example an emergency repair. If we balance the decreased cost in the tool-room under the second method against the increased cost of the idle time of productive machinery and labor, we shall find that we have lost more than we have gained. The same holds true for the construction of equipment for a new product in a case where time is essential.

Tolerances on Fixture Drawings. The drawings required in the tool-room under the first method of production need be functional ones only. Except on important dimensions of functional locations, etc., tolerances will be of doubtful value. Detailed drawings of the individual parts of fixtures must be supplied, yet tolerances and clearances on these details can be safely omitted. On the other hand, drawings to be used with the second method should include tolerances on all but atmospheric fits. The direction of the tolerances on those surfaces which are fitted at assembly should leave surplus metal. Those parts which assemble without fitting should have their dimensions and tolerances expressed in the same manner as on the component drawings of the interchangeable product itself.

The establishment of the tolerances on the functional locations is identical in all cases. Variations in these dimensions will be reproduced in the product itself. The effect of these will be to reduce the manufacturing tolerance. It is obvious that these variations must be in that direction which will hold the product within the established tolerances. Naturally, then, these tolerances should be kept as small as possible. The fixtures are usually made but once, while the product must be reproduced many times over. The amount of this tolerance on the jigs and fixtures should be a fair percentage of the component tolerance and 20 per cent should be sufficient in most cases. It is clear that the location of drill bushings for holes which may vary 0.020 inch is not so important as for holes which can vary but 0.002 inch.

It should be kept in mind that in many cases adjustment is provided on the machine tools to align the work-holding fixture correctly in relation to the cutting tool. Such is the case on milling, planing, and other similar machine tools. In the case of jigs for drilling and boring, however, no such adjustment is possible. Such equipment must, therefore, be constructed with greater accuracy than milling fixtures. It is thus apparent that the original tolerances and clearances for those surfaces machined on this type of equipment must be designated on the component drawings with great care. It is obvious that if

needlessly severe tolerances are required by the component drawings, the cost of the equipment will be greatly increased and no commensurate benefit will be derived from it.

Checking and Testing Jigs and Fixtures. The most effective method of checking jigs and fixtures is to set them up and make the required cuts on sample pieces. This, however, is not always possible and so model parts are a good substitute. Such parts are invaluable for checking purposes during the construction of any of the special manufacturing equipment. The final inspection of the completed fixtures should be a functional inspection only. The operating parts must function properly and the functional locations must bear the proper relation to one another. The component drawings, as well as the fixture drawing, should be consulted. Any fixture which will insure the proper machining of the component part is satisfactory as regards its accuracy. If the fixture drawing has been carefully completed, the information given there will indicate reasonable limits. If the fixture, however, exceeds those limits, but does insure the completion of the component part within the established tolerances, and without imposing over-severe conditions in the production, the fixture should not be rejected because of this technicality. It is well to keep a record of such deviations for reference. The purpose of this inspection is not to see how much fault can be found with the work accomplished, but to determine as surely as possible whether or not it will fulfill the purpose for which it is intended. This is never definitely determined until the fixture has actually produced satisfactory work.

Tolerances to be Allowed on Cutting Tools. In connection with Figs. 4 and 5, several sources of variations in the product were mentioned. Some of these errors are fixed quantities, others are variable. In discussing the cutting tools, we will consider two sources of variations — the first variable, the second practically fixed. The first source of error, which has been previously mentioned, is that due to the wear on the cutting edges of the tool. This, as we have seen, results in leaving more metal on the piece. Disregarding all other factors

of error, and assuming that the wear is equal on all surfaces, we should make the tools to the minimum metal sizes of the component drawings, in order to insure their longest life. When faces are neither male nor female, the initial size of the tool should be the mean dimension. But if a tolerance of, say, 20 per cent of the component tolerance has been permitted on the jigs and fixtures, the cutting tools should be made approximately the same percentage inside the minimum metal sizes of the component, except those made to the mean dimensions. Tools made to such dimensions should produce work within the established limits. If, however, sample parts made by such tools are beyond the established limits, they will vary outside of the minimum metal sizes. In such cases the tools can be salvaged, as metal must be removed from the tools to correct this fault.

The second source of variation in the product is initial error in the size or form of the tool itself. Tolerances for tools should be established from experience gained in actual practice as carefully as the tolerances are established for the components themselves. Cutting tools must be replaced over and over again in the course of production. On one hand, in order to reduce the first cost of these tools, their tolerances should be as liberal as possible. On the other hand, to lengthen their life and thus reduce the number of replacements, they should be held as close to the minimum metal limits as other conditions will permit. The economical balance between these two factors establishes the proper tolerances. In practice, the fixed error due to inaccuracies in machine tools and fixtures can readily be determined after production is under way. This error, properly added to or subtracted from the minimum metal limit of the component, establishes the maximum metal limit of the cutting tool. This maximum metal limit should be the basic dimension of the cutting tool. The application of the tolerance then establishes the minimum limit of new cutting tools. Whenever the established tolerance on the component is exacting, the tool should be made adjustable if possible, thus enabling wider limits to be established on the tools, reducing their initial cost

and prolonging their life. Such, for example, is the purpose of interlocking milling cutters.

Maintaining Tolerances on Tools Machining Several Surfaces. It is well to note that the more surfaces machined by a single tool, the more difficult it is to maintain close tolerances, either on the tool itself or on the product. Take, for instance, the cutting of a thread. If a die is used, the three main elements are carried on one tool; namely, the form, the lead, and the diameter. Adjustment for the diameter is possible, but the form and lead are fixed. Under present conditions, variations develop in the lead and shape when the tool is hardened and these are difficult and expensive to correct. As one die is replaced with another, these variations are different. If the tolerances on the component are sufficiently liberal, the use of dies is satisfactory. If they are severe, satisfactory dies are very expensive, although the direct production costs are low. In these cases, if the threads are milled or chased, the form alone is carried by the tool. Such a tool is readily and accurately made and maintained. The diameter is controlled by the setting of the tool, and is readily adjusted and readjusted. The lead is controlled by the lead-screw of the machine and is practically constant. Lead-screws can be obtained within any reasonable degree of accuracy.

Sufficient chip clearances must be provided on all cutting tools if a free cutting tool is to be obtained. The proper rate of the cutting edge should be determined as early as possible and carefully maintained. The design should be as simple and rugged as conditions will permit. The individual design and requirements of the cutting tools, of course, depend on the nature of the material to be machined and the methods of machining employed. The drawings of the cutting tools should be made with as much care and in conformity with the same basic principles as the component drawings themselves. When continuous production is involved, it is necessary to provide a constant supply of cutting tools. This supply of cutting tools must be available for instant use with as little adjusting or correction as possible.

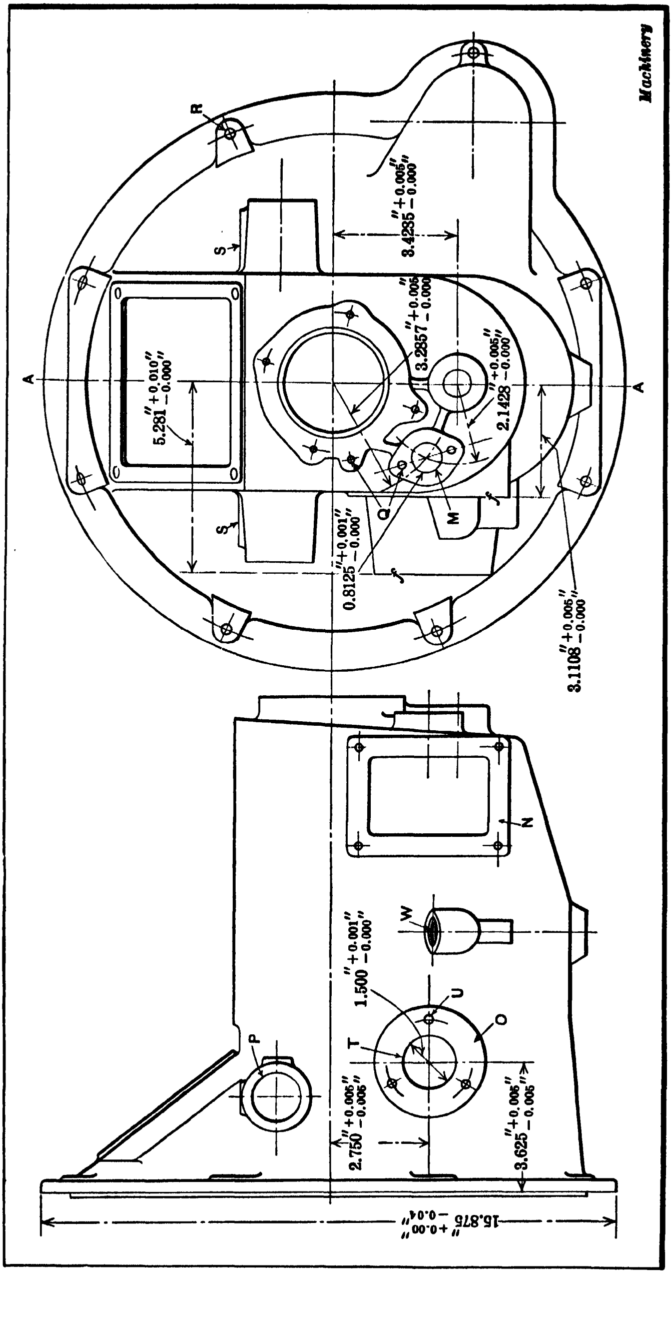


Fig. 14. Drawing of Automobile Transmission Case which requires Forty Machining Operations

Special Equipment for Machining Automobile Transmission Cases. In order to make clear the application of some of the principles stated, examples of properly designed jigs and fixtures will now be presented. For the first example, part of the special equipment required to manufacture the transmission case shown in Figs. 14 and 15 will be considered. As over forty operations in all are required to machine this case, space will

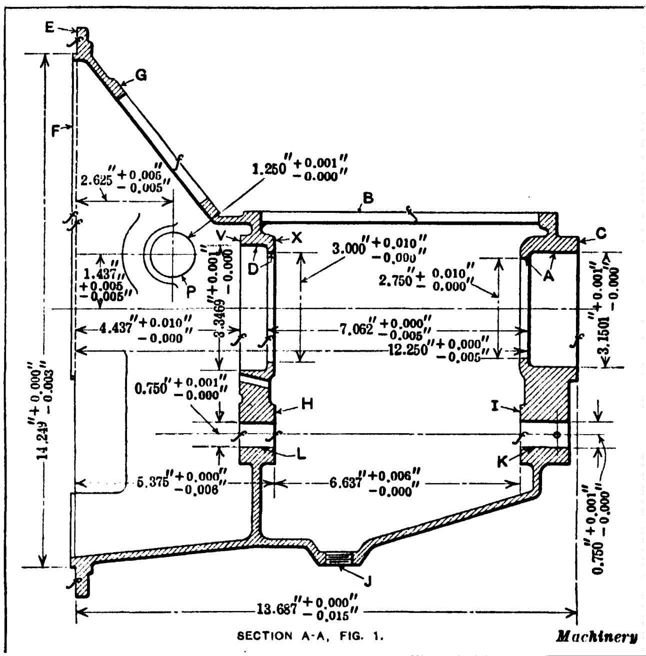


Fig. 15. Sectional View of Transmission Case

not permit a detailed discussion of each, but as many are either practically duplicate or are handled in well-known conventional ways, only the most instructive operations will be dealt with. The drawings shown in Figs. 14 and 15 are not complete, many dimensions and projections which do not affect the operations to be discussed having been purposely omitted. The first operation is to snag and chip the casting. This is a bench job and requires no special equipment. The second operation is to drill

the main bearing hole *A*, Fig. 15, as shown in the operation drawing, Fig. 16.

Operation drawings of this sort are of great value to the tool designer and also to the shop foreman and machine operator. Only the information required for a single operation appears on each drawing, thus making it handy for reference in the shop and also preventing any possibility of using a wrong dimension. They may be drawn to a much smaller scale than the component drawings and still contain information that cannot always be placed on the component drawing without danger of misuse. In practice, they are readily made. Small drawings of each projection of the work are made, and then the

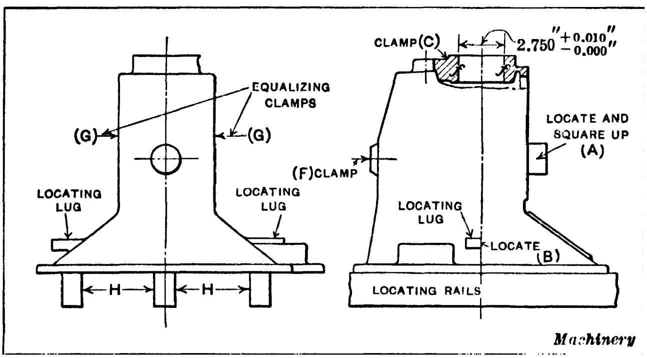


Fig. 16. Operation Drawing for drilling Main Bearing Hole in Small End

section or projection required for any particular operation drawing is traced and the required dimensions and notes added. Freehand tracings are often sufficient. No great amount of detail need be shown in these drawings. All that is required is enough to indicate the machined surface in question, the required register or locating surfaces, and the clamping points. On operations where little or no special equipment is required, no operation drawings are necessary. When these operation drawings are developed in conjunction with the operation lists described earlier in this chapter, a further advantage is gained. The work of designing the tools and fixtures can be readily and safely distributed among several designers, either in the same organi-

zation or in independent shops. When time is essential in commencing production, this factor becomes of great importance.

Jigs for Drilling Holes in Transmission Case. The first machining operation is important in several ways. As the surface machined at this time becomes the register point for many of the succeeding operations, it is necessary that the casting be carefully centralized in the jig, which is shown in Figs. 17 and 18. A study of these illustrations and the operation drawing shown in Fig. 16, will make clear the general con-

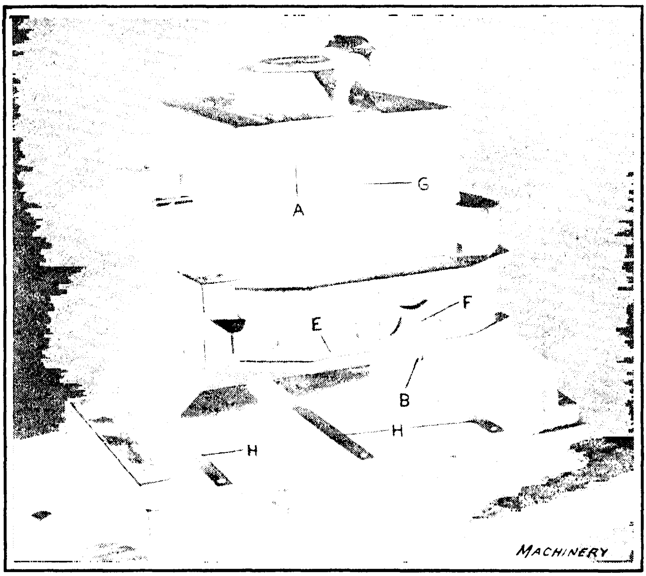


Fig. 17. Front View of Jig for drilling Main Bearing Hole in Small End

struction of the jig. The locating points and clamps are lettered alike on these three illustrations.

The operation of this jig is as follows: Leaf *E*, Fig. 17, being open, the transmission case is slid along the locating rails *H* until the shifter housing face *B*, Fig. 15, comes in contact with bar *A*, Fig. 17, and the locating lugs come in contact with the buttons *B*. This locates the case in one plane and also squares it up. Clamp-screw *C* operates on an angle against the fillet on boss *C*, Fig. 15, and holds the case down on rails *H* and also

against bar *A* (Fig. 17). Handwheel *D* (Fig. 18) operates the equalizing clamps *G* (Fig. 17) which both locate and clamp the case in another plane. The leaf *E* is then closed and the clamp-screw *F* which it carries is used to complete the rigid clamping of the case. Thus, the case is located and clamped in three planes. As this transmission case is a relatively large piece, the design of jigs and fixtures to clamp it with only one or two motions of the operator's hands would be a complicated and difficult task unless some type of hydraulic or pneumatic clamp-

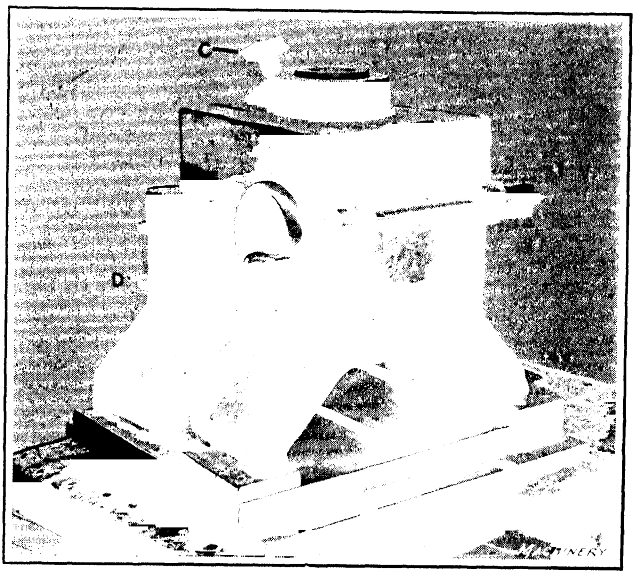


Fig. 18 Rear View of Jig, showing Mechanism for operating Equalizing Clamps.

ing mechanism were employed. This has been successfully accomplished in a simple and effective manner, but is not yet common practice. An example of such a jig will be presented later.

A drawing of the jig just described is shown in Fig. 19. It will be seen that stop *A* is pivoted to allow for inequalities in the casting. The equalizing clamps *G* are operated by levers which are actuated by nuts, one threaded right-hand, and the

other left-hand. These nuts are operated by means of similar threads on the handwheel spindle. It will be noted that this jig is rugged and simple, that all functional locations and parts are accessible, and also that the chip clearances are liberal, thus making

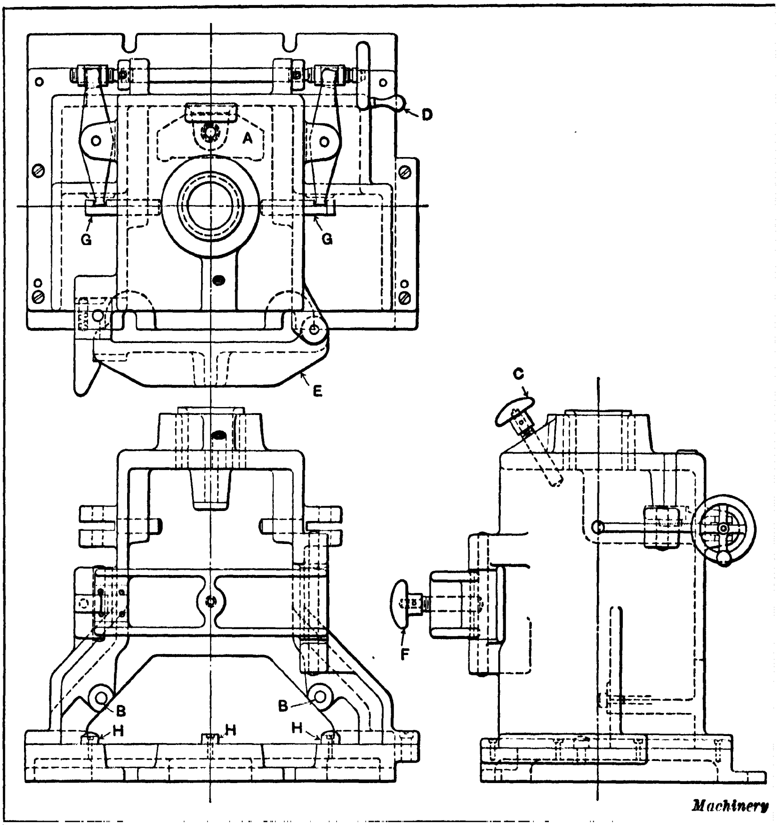


Fig. 19. Assembly Drawing of Jig illustrated in Figs. 17 and 18

a fixture that is readily cleaned and operated. It is also one that requires little attention in service.

The third operation consists of drilling and rough-counterboring the main bearing hole *D*, Fig. 15, and facing and turning flange *E* and boss *F*. This is done in a large Porter & Johnston lathe. An attachment to the spindle of the machine which runs in a cat-head at its outer end, locates the case on an arbor through the hole

drilled in the preceding operation and from the back of the flange. The case is also aligned and clamped around the outside of the flange. Two locating lugs cast on the bell of the case assist in locating and driving the work. These two locating lugs are removed after the machining is completed. The face of flange *E* and the center line of the main bearing holes *A* and

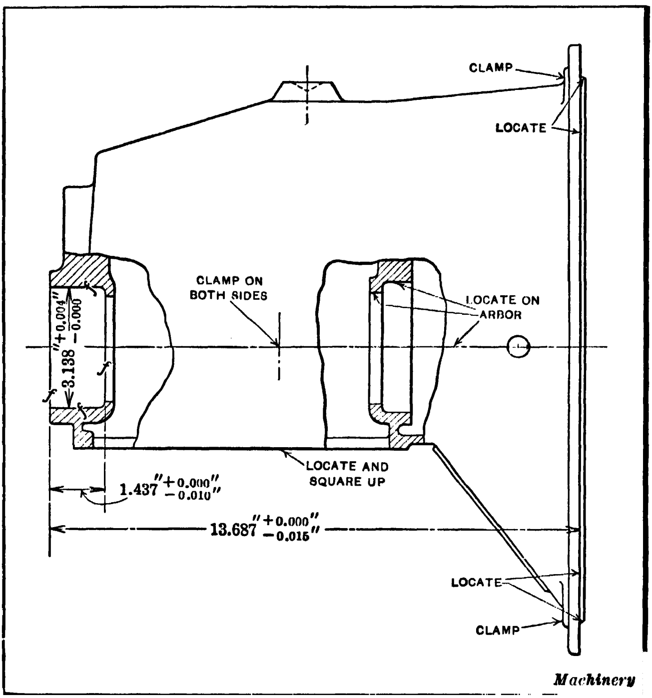


Fig. 20. Operation Drawing for counterboring the Main Bearing Hole in the Small End and facing the Boss

D now become the primary locating points for most of the succeeding operations.

Jigs and Tools Used in Various Operations. The fourth operation is performed on a boring mill and consists of facing the case to length and rough-counterboring hole *A*, Fig. 15. The operation drawing for this operation is shown in Fig. 20. The case is located in the jig shown in Fig. 21, by flange *E* and boss *F*, Fig. 15, and also on an arbor which passes through the

main bearing hole *D*. This arbor is hollow to receive the pilot on the boring-bar, thus helping to align it. The case is squared up by two studs *A*, Fig. 21, which bear on the shifter housing face *B*, Fig. 15, and is supported centrally and clamped by two

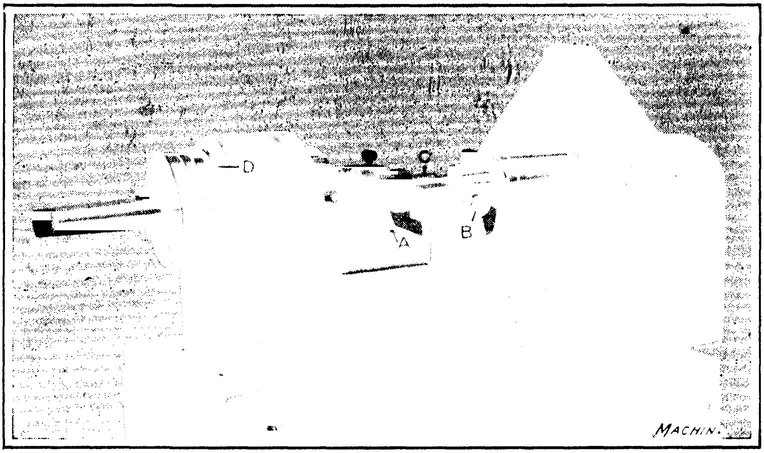


Fig. 21 Jig and Boring-bar used in machining Case to Length and counterboring Main Bearing Hole in Small End

clamp-screws *B*, Fig. 21. The bearing in the end of the jig is large enough to permit the boring-bar *C* to enter with the cutting tools assembled.

The boring-bar for this operation is shown in Fig. 22. Pilot

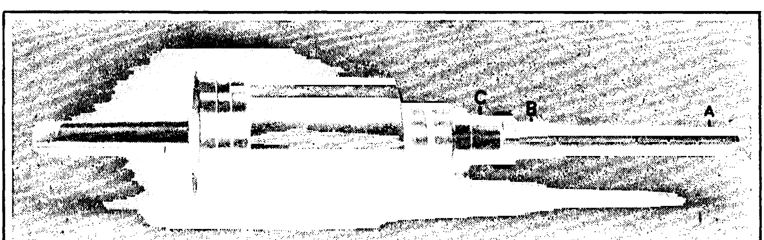


Fig. 22. Boring-bar disassembled from the Jig illustrated in Fig. 21

A enters the hollow arbor on the jig. Surface *B* carries a reaming tool which corrects the alignment of hole *A*, Fig. 15. Slot *C* carries a combined boring and facing tool which faces surface

C, Fig. 15, and so machines the case to length, and rough-counterbores hole *A*, Fig. 15. This makes a self-registering tool for the depth of the counterbore. It will be noted that this depth of counterbore is given in a different way on the operation drawing from the way it is shown on the component drawing. This is only a roughing operation, and it will be noted that stock is left for finishing. A later operation will bring the dimensions for this surface in accordance with the component drawing. Surface *D* on the tool, Fig. 22, runs in the large bearing in the fixture, while the lock-nut *E* is adjustable and acts as a stop for regulating the position of the facing tool. A little

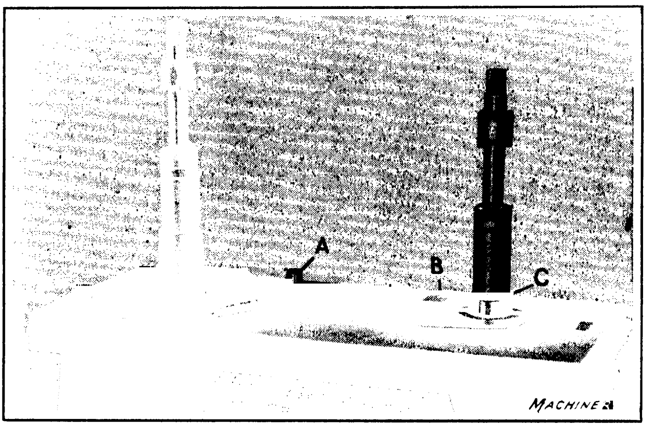


Fig. 23. Fixture employed in reaming both Main Bearing Holes of the Transmission Case

study will show that this arrangement will maintain the length of the case in accordance with the component drawing. The face of the flange is located against fixed points on the fixture. The face of the shoulder of the large bushing *D* is held in a fixed position in relation to the locating blocks on the fixture. Therefore, it makes a reliable registering point for a tool which must maintain a specified relation to these locating blocks.

The fifth operation is to mill the shifter housing face *B*, Fig. 15, and the clutch hand-hole face *G*. This is a straight milling operation performed on a large planer-type milling machine which machines a large number of castings at one time. The

sixth operation consists of hand-reaming the counterbores of holes *A* and *D*, Fig. 15, both for diameter and depth. The stand shown in Fig. 23 is provided to hold the case and to pilot the tools while hand-reaming. The case is placed on the arbor shown at the left to ream counterbore *A*, Fig. 15, with the face of flange *E* resting on the locating blocks. The pin *A*, Fig. 23, enters a hollow lug at the large end of the case to prevent it

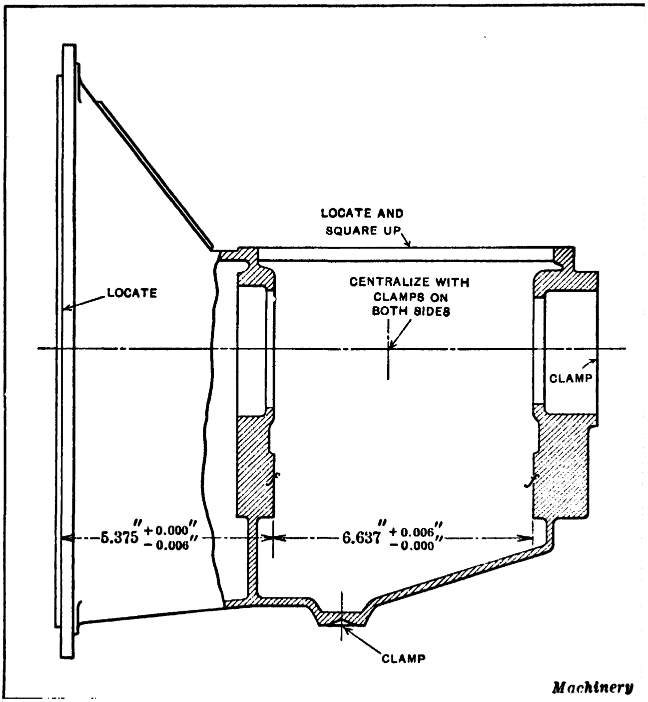


Fig. 24. Operation Drawing showing Methods of locating and clamping Work for Seventh Operation

from rotating. The end of the arbor acts as a stop for the reaming tool, thus maintaining the conditions called for on the component drawing. The case is then inverted and placed on the arbor shown at the right in Fig. 23 to ream counterbore *D*, Fig. 15. The block *B* rests against the shifter housing face *B*, Fig. 15, to prevent rotation of the case. The bottom of the counterbore finished on the other arbor rests on shoulder *C*,

while the end of the arbor acts as a stop for the reamer, thus maintaining the location of the bottom of this counterbore in accordance with the information on the component drawing.

Operations on Vertical Milling and Profiling Machines. The seventh operation consists of milling surfaces *H* and *I*, Fig. 15, and the corresponding surfaces around the idler shaft hole *M*, Fig. 14. This operation is performed on a vertical milling machine equipped with an auxiliary cutter-head to reach down into the case. The operation drawing for this job is shown in

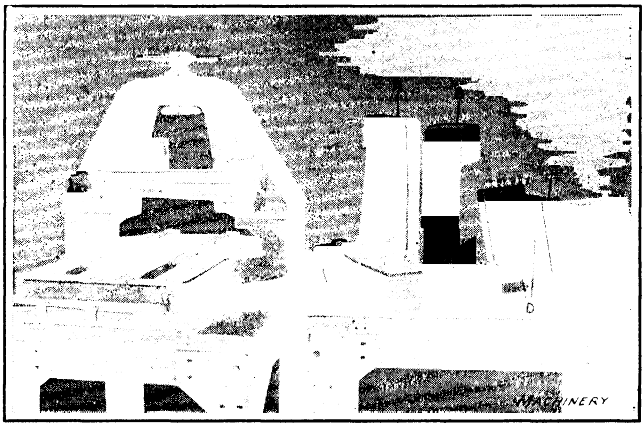


Fig. 25. Fixture used in Milling Operation on Case, and Parts for supporting Auxiliary Cutter-head

Fig. 24. The fixture used for this operation is shown at the left in Fig. 25. The case is located in one plane on the flange, squared up and located in the second plane on the shifter cover face *B*, Fig. 15, and located in the third plane by being centralized on the body. The center line of holes *A* and *D*, Fig. 15, is not used as a locating point for this operation, for two reasons: First, the requirements of the surface milled in this operation are that they be parallel to the flange and that they be maintained at the specified distance from the flange and from each other. Therefore, the location of the case in relation to the main bearing holes is unimportant. The second reason is that the use of an arbor in this fixture would greatly increase the amount of time required to load and unload the work. The case is clamped on

surface J, Fig. 15, by the leaf and on surface C by the clamp-screw.

The construction of the auxiliary cutter-head is shown in Fig. 26. The driving spindle E fits into the spindle of the vertical milling machine and drives the cutters F and G through a train of gears.

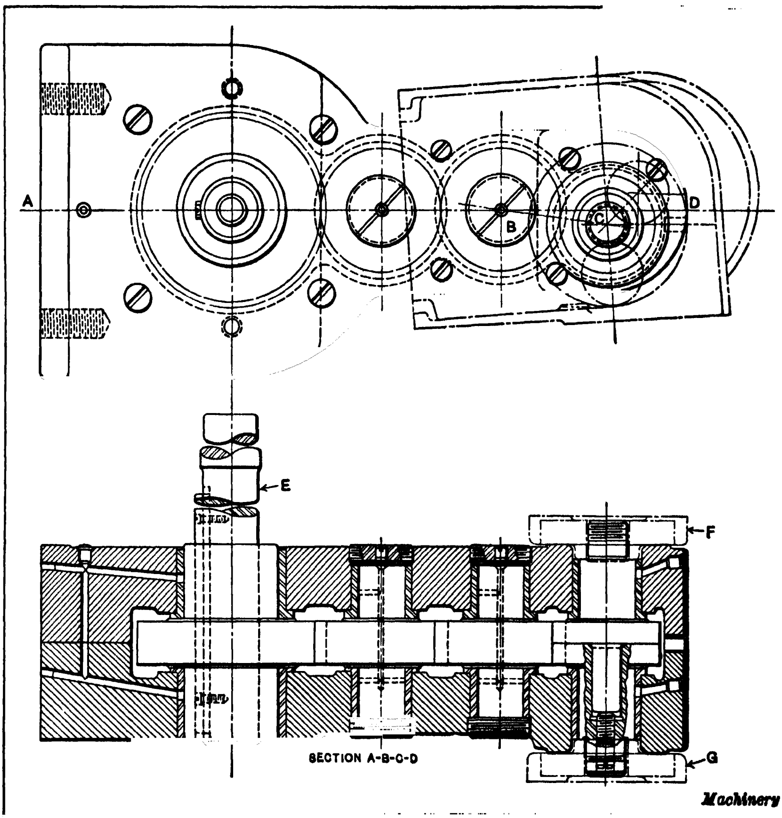


Fig. 26. Auxiliary Cutting Head used in milling Surfaces on Inside of Case

The drawing of this cutter-head should be self-explanatory. The cutter-head is supported by a bridge composed of pieces A, B, and C, shown at the right, Fig. 25, which is clamped to the milling machine, as shown in Fig. 27. Support B is clamped at the proper height on the dovetail of the machine column. Support A is clamped to the dovetail on the knee of the machine, while bridge C is sup-

ported on the tops of the two supports. The auxiliary cutter-head is then fastened on surfaces *D*. Vertical adjustment is provided for the outer end of the bridge which rests on *A*, while none is required at the other end.

The knee of the milling machine is adjustable up and down to control the position of the cuts, and as support *B* holds a fixed position in relation to the machine while *A* moves with the knee, it is necessary to provide the adjustment for the outer

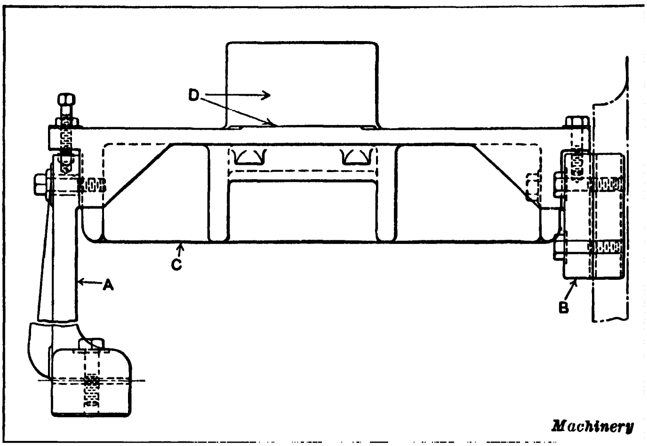


Fig. 27. Assembled View of Parts clamped on Milling Machine to support the Auxiliary Cutting Head

end at *A*. The fixture, Fig. 25, is attached to the table and fed, with the table, to the cutters. Attention is called to the fact that the loading side of the fixture is on the side farthest from the cutters. This arrangement enables the feed of the table to be kept to a minimum.

The eighth operation consists of milling the outside boss around the idler shaft hole *M*, Fig. 14, on the small end of the case. Ordinarily, this operation would be performed on a vertical milling machine, or with a facing tool on a drilling machine. In this particular case, however, profiling machines were available, while vertical milling machines were not. Furthermore, this cut is a relatively light one, which a profiling machine can handle satisfactorily, and so this type of machine is used. This

indicates to a certain degree how the design of the equipment is determined by the machine tools available. The fixture for this operation is shown to the right in Fig. 28. The case is located on the face of flange *E*, Fig. 15, and by boss *F*, and is clamped on the back of the flange. This is an instance where a pneumatic or hydraulic clamping device could be used to great advantage and save fully half the setting-up time.

The fixture not only consists of a work-holding device, but also acts as the stand for the working gage. Lug *A* is used for registering the position of the cutters and also for registering the flat step-gage *D* which is used to test the finished height of the boss. Because the maximum distance between the table

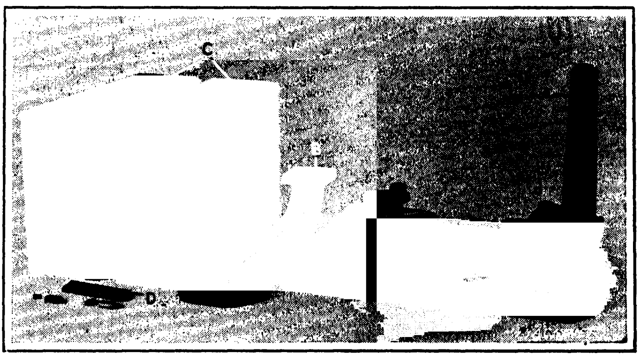


Fig. 28. Equipment provided to adapt a Profiling Machine for a Milling Operation on the Case

of the profiling machine and its cutter-spindles was not great enough, raising blocks *C* were provided to lift the heads of the machine sufficiently to permit the transmission case to be machined. Bracket *B* was also required to support the end of the operating handle shaft in its raised position.

Drilling, Reaming, and Milling Operations. The ninth and tenth operations, respectively, consist of drilling and reaming the countershaft holes *K* and *L*, Fig. 15. Both of these operations are performed on horizontal radial drilling machines, and the work-holding fixtures employed in each case are practically identical in design. The jig for the tenth operation is shown in Fig. 29. The case is located on the face of flange *E*, Fig. 15,

and on arbors through the main bearing holes *A* and *D*, and is squared up by two equalizing plungers which bear on surface *B*. The case is clamped by the end of the hollow arbor *B*, Fig. 29, which is drawn back against the bottom of the counterbore *A*, Fig. 15. Arbor *A*, Fig. 29, which passes through *B* contains a groove which receives leaf *F*. Thus, when arbor *A* is drawn up by the clamping nut *C*, this leaf is drawn up against the end of arbor *B*, clamping the case between the face of the flange and the bottom of the counterbore previously referred to. When leaf *F* is swung aside, arbor *A* is withdrawn. Bracket *D* is provided to support the end of the arbor *A* in its loading position. Handles *G* and *H* are used to wring the arbors into

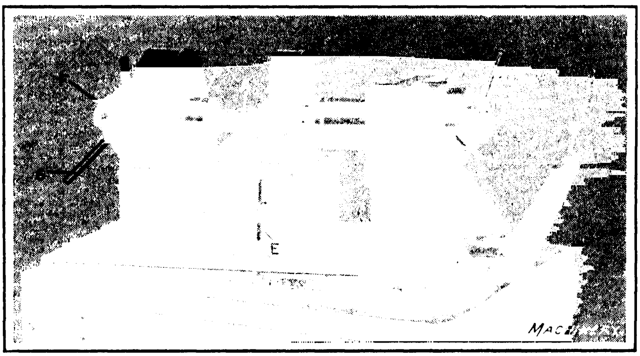


Fig. 29. Work-holding Fixture for Drilling and Reaming Operations on Radial Drilling Machine

the case, as these arbors are a very close fit in the counterbores which are held to a tolerance of 0.001 inch. Handle *E* operates the equalizing plungers which bear against surface *B*, Fig. 15, and square up the case. The eleventh operation consists of drilling and reaming the idler shaft hole *M*, Fig. 14. A very similar jig is used in this operation, the principal difference being that the case is squared up by a plug in countershaft hole *K*, Fig. 15, instead of by equalizing plungers acting against surface *B*.

The twelfth and thirteenth operations, respectively, consist of milling the surfaces of the tire pump face *N* and pedal support boss *O*, Fig. 14. Both of these operations are performed

on a profiling machine, and the same fixture is used. This fixture is shown in Fig. 30. The case is located on holes *A* and *D*, Fig. 15, by arbor *A*, Fig. 30, and hollow plug *B*, and on surface *C*, Fig. 15, by shoulder *C*. It is squared up by the pin *D* projecting into hole *K*, Fig. 15. Two screws *E* are adjusted to suit surface *B*, Fig. 15, to support the case against the clamping device *F*, Fig. 30. The spring plunger *G* is locked by the clamp-screw *H* and supports the case against the thrust of the cutters. Arbor *A* has a bayonet cam-slot which engages a stud in the hollow plug *B*, clamping the case between the bottom

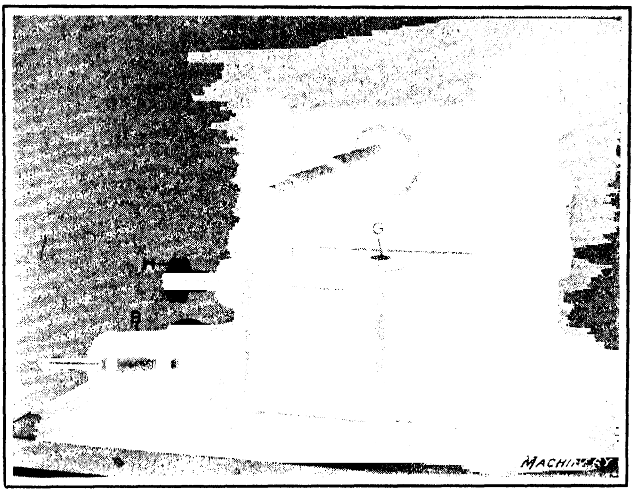


Fig. 30. Another Fixture provided for a Milling Operation on a Profiling Machine

of counterbore *D* and surface *C*, Fig. 15. Stud *K* is the register point for the tool when milling the pedal support boss, while stud *L* is the register point for the tool when milling the tire pump face. Due to the position of this fixture on the machine, all of the operating handles must be on the front or on the sides. This is the reason for the extensions to the two clamps which are carried through the side of the fixture.

In the fourteenth operation, the clutch shaft hole *P*, Figs. 14 and 15, is drilled and reamed. This operation is performed on a boring mill. The jig, with slip bushings for the reamers,

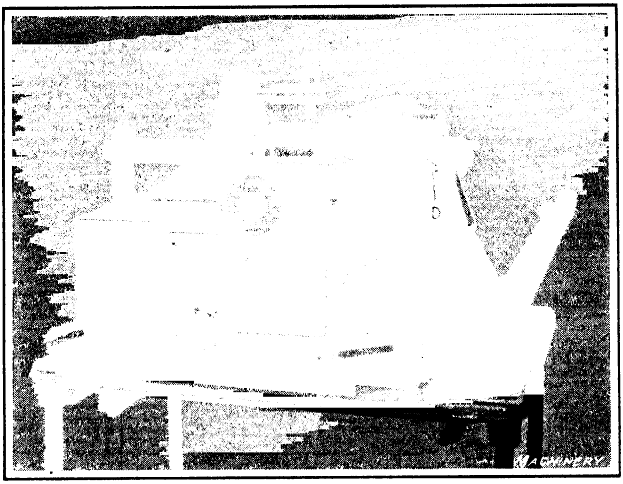


Fig. 31. Jig employed in Drilling and Reaming Operations on a Boring Mill

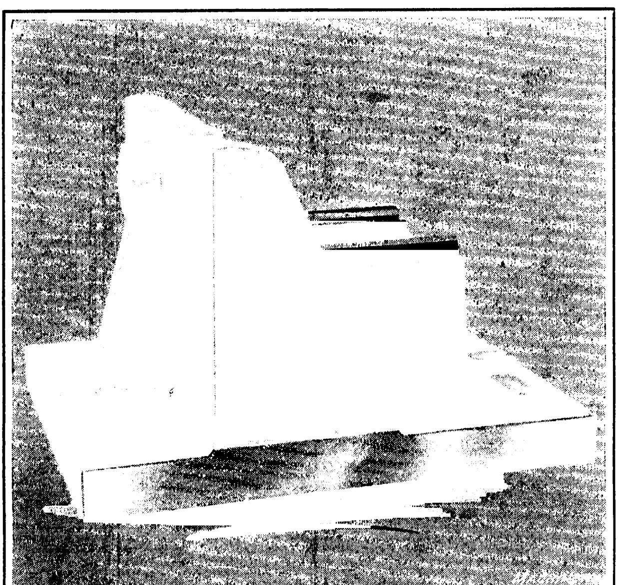


Fig. 32. Simple Stand provided for Supporting Case during Operations on Drain Plug Hole

is shown in Fig. 31. The case is located by the usual register points, on the main bearing bore and counterbore *D*, Fig. 15, and on the flange *E*. It is squared up by the countershaft hole *L*, and clamped from the small end against the face of the flange. A groove at the end of arbor *A*, Fig. 31, receives leaf *B*. Clamp-nut *C* draws the arbor back, thus clamping the case between surface *C*, Fig. 15, and the face of the flange. Leaf *B* is swung aside when unloading, thus permitting arbor *A* to be withdrawn.

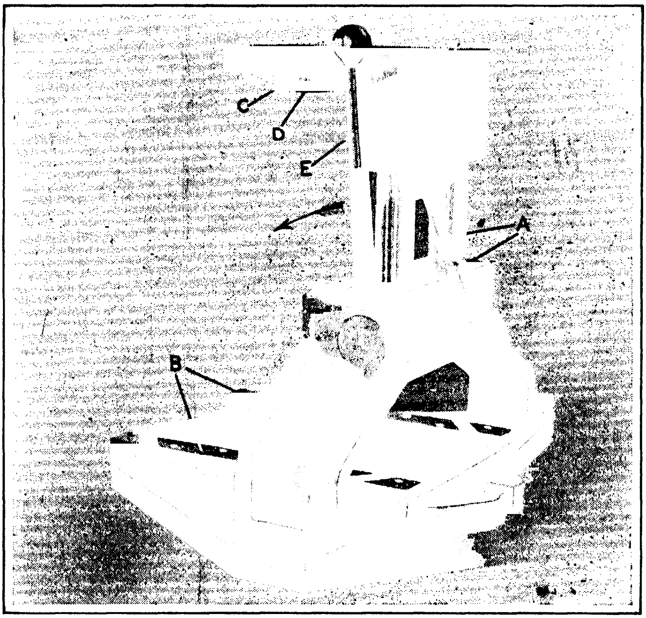


Fig. 33. Drill Jig used for drilling Seven Small Holes in Transmission Case at One Time

Bracket *G* supports the shoulder of the large arbor in its withdrawn position. Handle *D* is provided to assist in wringing the large arbor into the case. Lug *F* enters the case through the opening in the shifter housing face *B*, Fig. 15. Plug *E*, Fig. 31, wrings into the countershaft hole *L* and into the lug *F* to align the case.

The fifteenth operation is performed on a drilling machine, and consists of drilling, tapping, and counterboring drain plug

hole *J*, Fig. 15, and facing the surface of its bore. The exact location of this drain plug hole is of no importance. A conical spot is cast in the boss which is used to locate and center the drill point. The simple stand shown in Fig. 32, unprovided with bushings or clamps, supports the case on the drilling machine table. Further elaboration of this simple design would not improve its effectiveness in any way. The drilling machine is fitted with a quick-change collet to permit the operator to change the drill, tap and facing tools rapidly.

Jigs for Drilling a Number of Holes at One Time. The sixteenth operation on the transmission case consists of drilling

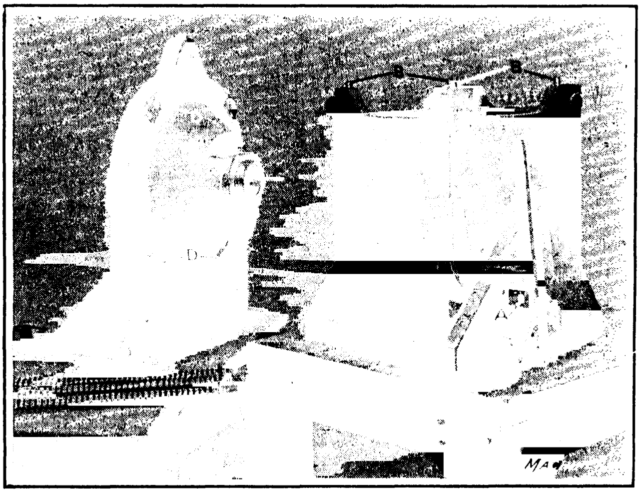


Fig. 34. Cradle Jig and Cluster Plate employed in drilling Twelve Holes on a Multiple-spindle Drilling Machine

seven small holes *Q* (see Fig. 14) in the small end of the case. This operation is performed on a single-spindle drilling machine equipped with a special multiple drill head. The jig used is illustrated in Fig. 33. The face of flange *E*, Fig. 15, rests on rails *B*, while the large stud *C* enters the main bearing counterbore *A*, Fig. 15, and the small stud *D* enters the idler shaft hole *M*, Fig. 14, thus centering and squaring the case. The operating handle *E* is pulled forward and down as indicated by the arrow, thus lowering the head by means of the crank and con-

necting-rod *A*, and clamping the case during the drilling operation. The operator holds handle *E* down with one hand while he operates the drilling machine with the other. Attention is called to the commendable features of this jig, which include simplicity of design, accessibility of all functional surfaces, chip clearances, and rapid operation.

The seventeenth operation is performed on a multiple-spindle drilling machine provided with a lifting table, and consists of drilling eight holes *R*, Fig. 14, and four holes around hole *D*, Fig. 15. The jig used for this operation, together with the cluster plate for guiding the drills, is shown in Fig. 34. These parts are shown assembled in Fig. 35. The jig is in the form of a cradle to permit it to be tipped for removing and inserting the product. Otherwise the table of the machine would have to be lowered an excessive amount to accomplish the same result.

The case is located by an arbor through the main bearing holes *A* and *D*, Fig. 15, and rests on surface *C*, Fig. 15. The jig is rocked to its drilling position and locked there by the spring plunger *A*, Fig. 35. Four spring plungers *B* rest against the back of the flange, and are locked in position by clamp-screws. These support the flange against the thrust of the drills. The case is located radially by stud *E* which enters countershaft hole *K*, Fig. 15. The cluster plate slides on the column of the drilling machine, and is held down by the springs on the three supporting rods *F*, while the washers at the end of these rods limit its downward travel. As the table of the machine is raised, the arbor in the jig enters hole *C* in the cluster plate, Fig. 34, thus aligning the case, while blocks *D* press against the face of the flange of the transmission case, clamping it in position. This makes a simple and quickly operated jig. As the table is raised toward the drilling position, the work is clamped, and as the table is lowered, the work is automatically unclamped. This automatic clamping feature effects a considerable saving in time when setting up work.

The eighteenth operation consists of drilling six holes in surface *B*, Fig. 15, and two holes in bosses *S*, Fig. 14. This opera-

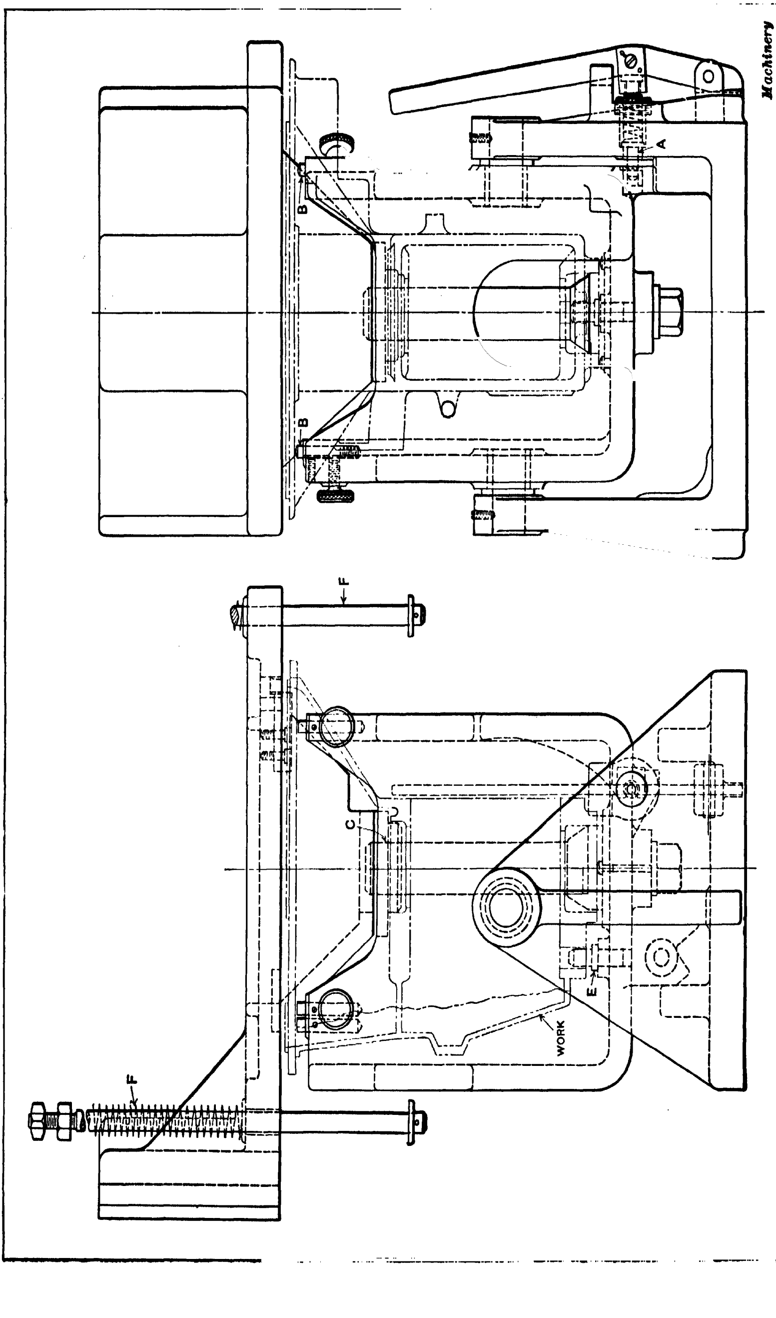


Fig. 35. Assembled Drawing of Cluster Plate and Jig shown in Fig. 34

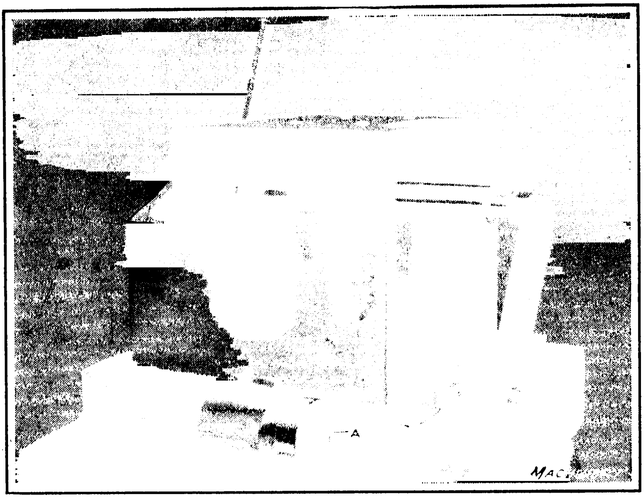


Fig. 36. Another Drill Jig for drilling a Number of Holes at One Time on a Single-spindle Drilling Machine having a Special Head

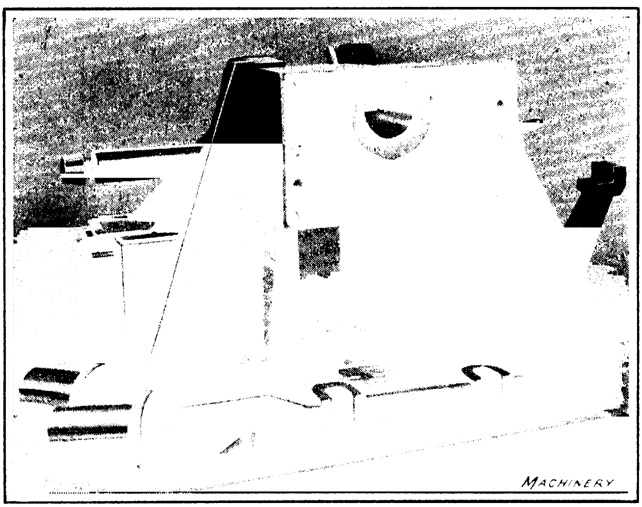


Fig. 37. Jig used for drilling and Reaming Operations performed on Boring Mill

tion is performed on a single-spindle drilling machine equipped with a special multiple-spindle drill head. The jig is of the box type, as shown in Fig. 36. The case is located on an arbor

through the main bearing holes *A* and *D*, Fig. 15, radially by a stud in countershaft hole *K*, and is clamped from the bottom of counterbore *D* against surface *C*, Fig. 15. The hollow plug *A*, Fig. 36, fits over the arbor into the main bearing counterbore *D*, Fig. 15. Leaf *B* is then swung under the washer and bears against the end of the hollow plug as clamp *C* is tightened. This leaf has the same function as a slotted washer and is employed in place of such a washer to eliminate an additional loose piece on the jig.

The nineteenth and twentieth operations are similar drilling operations on small holes, performed on single-spindle drill-

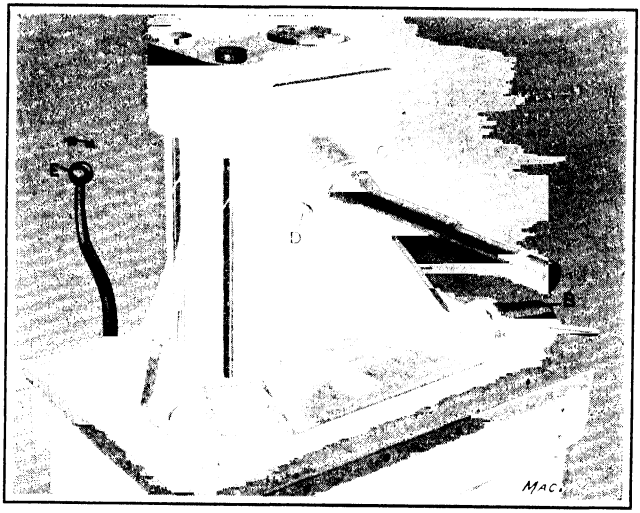


Fig. 38. Drill Jig provided for drilling Three Small Holes in Pedal Support Boss

ing machines equipped with special multiple-spindle drill heads. The transmission case is held in simple jigs for both of these operations. The twenty-first operation consists of drilling and reaming hole *T*, Fig. 14, and is performed on a boring mill. The fixture for this operation is shown in Fig. 37. The holding points and methods of clamping are identical to those of the fixture shown in Fig. 31. The twenty-second operation consists of drilling holes *U*, Fig. 14, on a single-spindle drilling

machine provided with a special multiple-spindle drill head. The jig shown in Fig. 38 is similar to the one shown in Fig. 33. The transmission case is located from the main bearing holes *A* and *D*, Fig. 15, by arbor *A* and hollow plug *B*. Surface *V*, Fig. 15, is held against shoulder *C* by the shoulder of the hollow plug acting against face *C*, Fig. 15. The plug is held by a stud which engages the bayonet cam-slot in arbor *A*. The case is located radially by stud *D* which enters countershaft hole *L*, Fig. 15. The operating handle *E* is moved as indicated by the arrow, which lowers the head *F* carrying the drill bushings and also a stud which enters hole *T*, Fig. 14.

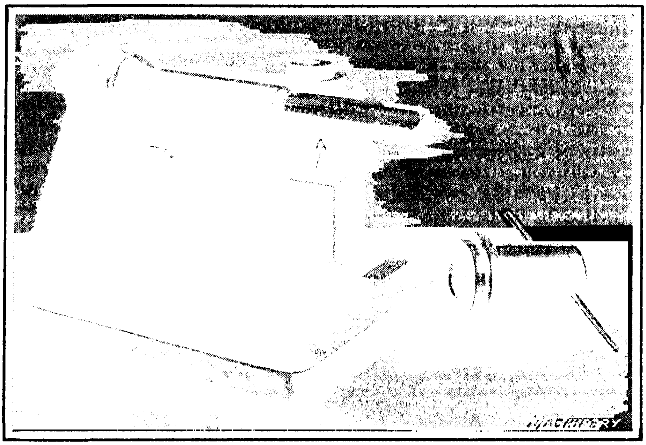


Fig. 39. Equipment employed in performing Various Operations on Filler Hole

Operations on Filler Hole. The twenty-third operation consists of drilling, chamfering, spot-facing, and tapping filler hole *W*, Fig. 14. This operation is performed on a single-spindle drilling machine by means of the jig shown in Fig. 39. The case is located on an arbor through the main bearing holes *A* and *D*, Fig. 15, and clamped against surface *C*, Fig. 15, in the usual manner. It is located radially by a stud which enters the countershaft hole *K*, Fig. 15. The spring plunger *A*, which is locked by the clamp-screw *B*, supports the under side of the filler boss against the thrust of the cutting tools. The drilling

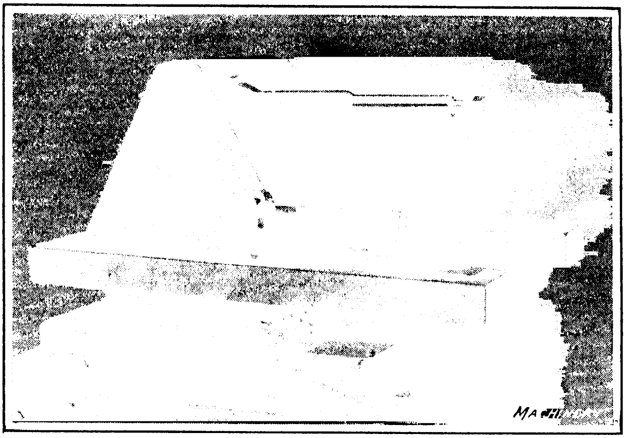


Fig. 40. Fixture equipped with Trunnioned Roller Bearings, used in tapping Holes



Fig. 41. Pivoted Ball-bearing Fixture used in Tapping Operation

machine is equipped with a quick-change collet attachment to promote the speedy change of tools.

The next six operations are all minor drilling operations requiring simple jigs. The thirtieth operation consists of countersinking all the holes to be tapped in succeeding operations with a small electric hand drill, equipped with the proper countersinks. No special work-holding device is required. The thirty-first and thirty-second operations are tapping operations performed on a tapping machine, without the use of special

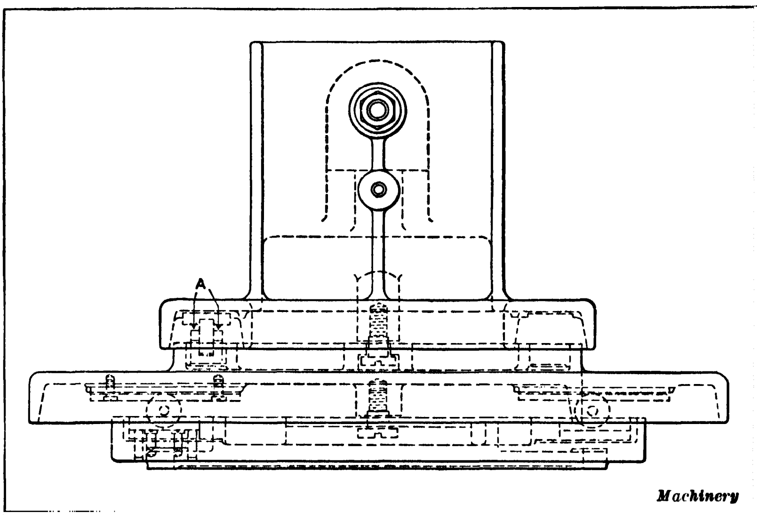


Fig. 42. Drawing of Tapping Fixture illustrated in Fig. 40, equipped with Trunnioned Roller Bearings

fixtures. The eight remaining machining operations are tapping operations for which fixtures are provided. Some of them are simple stands, while others are mounted on ball or roller bearings to make lighter work for the operator in shifting the jig from position to position. Two of these jigs will be described.

Jigs Provided for Tapping Operations. The thirty-fourth operation consists of tapping the six holes previously drilled in face *B*, Fig. 15, and is performed on a tapping machine. The fixture is shown in Fig. 40. The transmission case is located on an arbor through the main bearing holes *A* and *D*, Fig. 15,

and is squared up by a stud which enters the countershaft hole *K*, Fig. 15. The fixture is mounted on two sets of roller bearings which permit it to be readily rolled in two directions. The construction is shown in Fig. 42. In order to make the travel of the rolls as short as possible, they are made with two small trunnions as shown at *A*. These trunnions roll on the bottom rails, while the large periphery of the rolls is in contact with the upper rails. The effect of this construction is that the upper part of the fixture can move about six inches while the

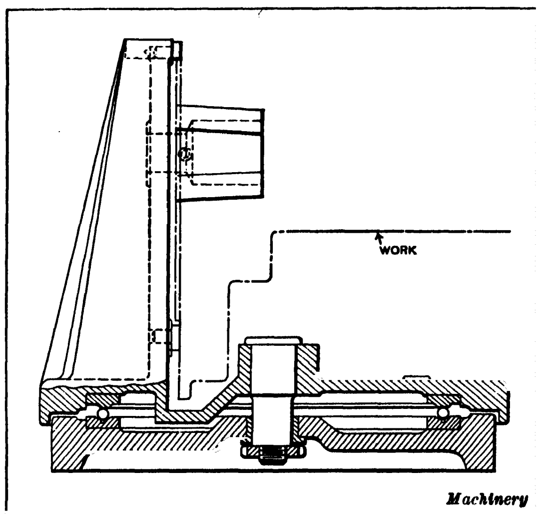


Fig. 43. Pivoted Ball-bearing Fixture shown in Fig. 41

rolls have moved only about one inch. The lower rails are shorter than the upper ones in the lower sections of the fixture.

The thirty-seventh operation consists of tapping holes *U*, Fig. 14, and is performed on a tapping machine by means of the fixture shown in Fig. 41. The case is supported on an arbor through the main bearing hole *D*, Fig. 15, and is clamped and squared up against the face of flange *E*, Fig. 15, by a slotted washer which bears against face *X*, Fig. 15. This washer is drawn back by a clamp-nut on the plunger through the arbor. The case is located radially by the stud seen in Fig. 41, which enters countershaft hole *L*, Fig. 15. The upper part of the

fixture is pivoted and revolves on a large ball race, as shown in Fig. 43.

The foregoing descriptions of some of the special manufacturing equipment for an automobile transmission case have not been given for the purpose of illustrating how such a part may be machined, but rather to indicate in some degree the many factors which must be considered in the design of any special manufacturing equipment. These descriptions are incomplete, yet a careful study of the component drawing and the illustrations will supply many of the omissions in the descriptions. With few exceptions, no mention has been made of the cutting tools, as these have been for the most part standard mills, boring-bars, drills, taps, reamers, or similar standard tools.

Attention is called to the general grouping of the operations. First, the boring and facing, next the milling, then the drilling and reaming of the larger supplementary holes, followed by a few profiling operations. The final operations consist of drilling and tapping the many smaller holes. For large production, the machine tools required would usually be so grouped that the parts would pass consecutively from one operation to the next. For smaller rates of production where the machine tools are not kept set up constanly for one operation, they are often grouped together by types of machines. In either case, the foregoing general arrangement of operations would be satisfactory. A few minor changes in sequence might be made to advantage, but the general lay-out would remain unchanged. In order to cover some points which the foregoing examples have not touched upon, a few examples of tools and several additional fixtures will be presented. These will indicate possibilities in design, which effect savings in direct labor costs.

Pneumatic Clamping Devices. It has been pointed out that the use of pneumatic or hydraulic clamping devices is necessary on many fixtures for large parts, if the clamping is to be performed by a single movement or two of the operator. The best known examples of pneumatic clamping devices are air chucks.

Fig. 44 shows a drill jig, together with the part that is to be drilled; this is clamped by air pressure. A flexible hose, attached to the air line, is connected with this fixture by part *A*. The part to be drilled is slid into the jig from the right, with the machined face down. The opening of a valve operates four pistons, one built into leaf *B*, one in leaf *C*, and the others on the back of the fixture which operates clamps *D* and *E*. These hold the part firmly in position while the holes are being drilled. Sight-holes are provided so that any mislocation of the part is

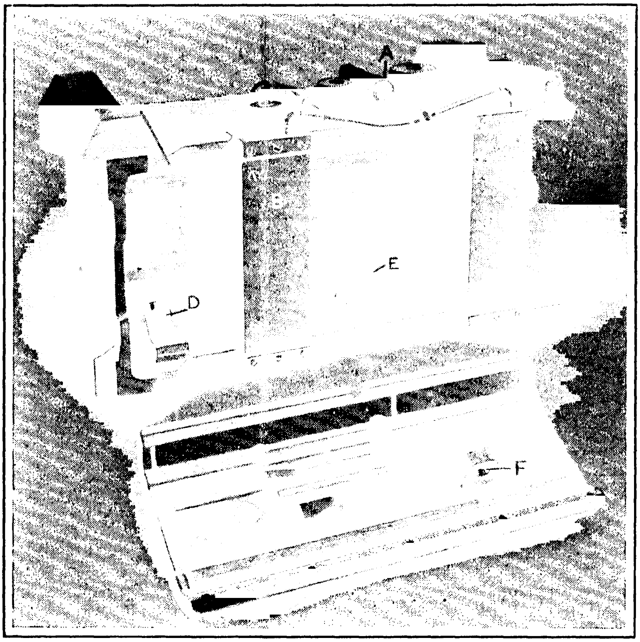


Fig. 44. Drill Jig equipped with Air-operated Clamping Devices

readily detected. As a further safeguard against movement of the work, the large hole *F* is first drilled, and a plug is then inserted in it through the bushing. This jig is easily and rapidly operated, and the design of the clamping pistons is as simple as that of any other clamping device would be.

There are ocasions when a convenient air line is not present, or where the attachment of a flexible hose would interfere with

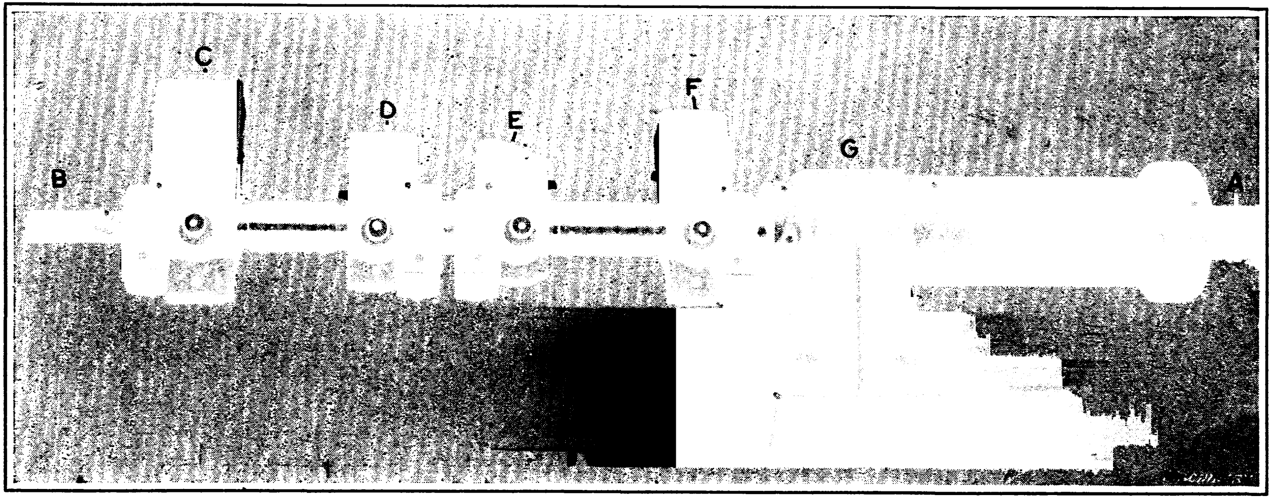


Fig. 45. Multiple-tool Facing Bar used in facing Four Bosses of a Machine Tool Spindle Head

the efficient handling of the fixture. To take care of such conditions, fixtures have been made with a hydraulic clamping device, constructed in a similar manner to the pneumatic ones. The pressure is obtained by means of a small hydraulic jack arrangement, which is built into the fixture and operated through the medium of a cam-lever or screw.

Multiple-tool Facing Bar. An interesting facing bar is shown in Fig. 45. This consists of a hollow spindle, on which the tool-holders are clamped, through which passes a bar marked *A* at the right

end in the illustration and *B* at the left. This bar carries four tool-holders *C*, *D*, *E*, and *F*, and is used to face the bosses on the spindle head of a machine tool. The head to be machined

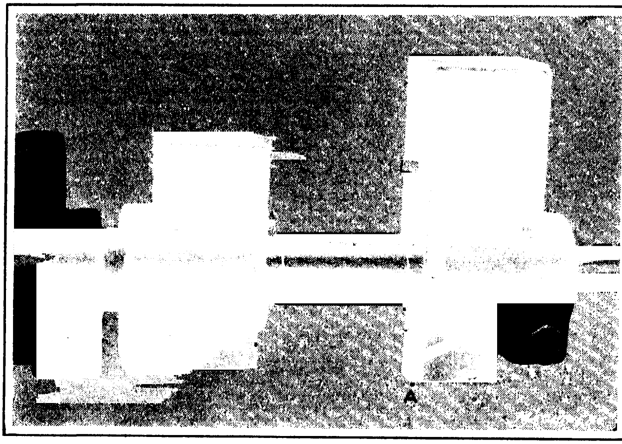


Fig. 46. Close-up View of One of the Facing Bars in Fig. 45, showing Grooves used in feeding Cutter across the Surface

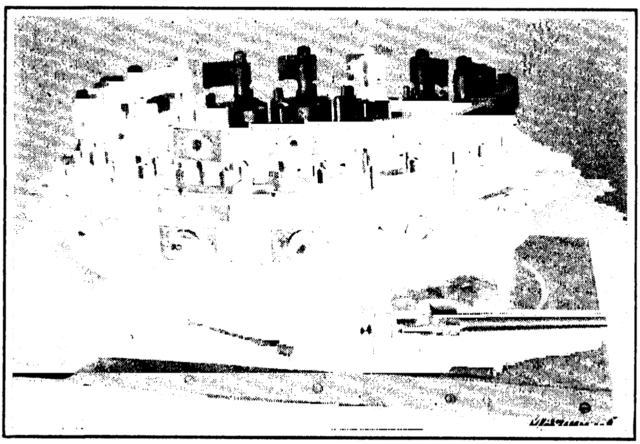


Fig. 47. Typical Example of Fixtures used in Continuous Milling Operations for producing Parts in Large Quantities

is clamped in position on the table of a boring mill with the facing bar in position, and the bearing caps are then assembled. Bracket *G* is also clamped to the table of the machine

to prevent endwise movement of the outer spindle. As the facing bar revolves, the inner bar is fed in, which feeds the facing tools carried in the tool-holders into the faces of the bosses. This is accomplished by means of angular tongues (such as may be seen at end *B* on the inner bar) sliding in angular grooves (such as shown at *A*, Fig. 46), which are cut on the tool-holders. The outer spindle is relieved to permit the facing tools to pass beyond the inside edges of the faces of the bosses. The tongues and grooves are so cut that when one tool has

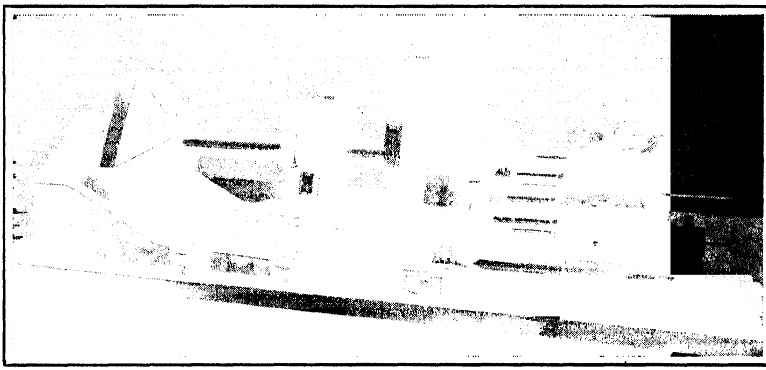


Fig. 48. Continuous Drilling Fixture having Three Work-holding Stations

traveled its full distance, it stops close to this relief until all the other tools have finished cutting. The cutting edge of the tool has then traveled beyond the face of the boss so that it does not score the face by dwelling there. After all the tools have completed their cuts, the work is removed from the machine and the facing tools returned to their starting position by withdrawing the inner bar. The tools are adjustable, which enables the lengths and relative positions of the bearings to be accurately maintained. With this tool, several bosses can be faced in little more time than one.

Milling and Drilling Fixtures. Fixtures and machines for continuous milling operations are chiefly used where the production of any large quantity of parts is required. An example of such a milling fixture is shown in the illustration Fig. 47. When these fixtures are used, the machine is working constantly in-

stead of being idle during the time the operator is engaged in removing the finished parts and inserting new work in place in the fixture.

While continuous milling fixtures are quite common, similar drilling fixtures are not so well known. Fig. 48 shows such a fixture designed to be used on a single-spindle drilling machine; the fixture is mounted on the machine in a vertical position. The special multiple-spindle drill head *A* is driven by the spindle of the machine and also raised and lowered in the usual manner by the machine spindle. The bars *B* guide the head and also prevent it from rotating. The two brackets *C* and *D* are bolted to the column of the machine, the bracket *D* containing bushings to assist in the alignment of the drills. The special table *E* is also bolted to the column of the drilling machine, in place of the standard table. The jig is pivoted and supported by the bracket *D* and table *E*. This jig contains three work-holding stations, so that while drilling one piece, the operator removes and inserts parts in the other stations, thus obtaining a much higher production rate.

All the foregoing examples of special manufacturing equipment are used for relatively large parts, but the same general principles apply equally to small pieces. Certain detailed practices which are sometimes followed for one class of work are not always feasible when the size of the parts becomes much larger or smaller. The fundamental problems, however, are the same, and economical solutions require the careful use of the same basic factors.

CHAPTER IX

GAGES IN INTERCHANGEABLE MANUFACTURING

A GAGE is an instrument or apparatus for measuring a specific dimension. Every manufactured part is measured during its production and after its completion, in one way or another. This applies equally to a single piece made for a special machine or as a repair part, or to a hundred thousand duplicate parts manufuctured for an interchangeable product. The mere removing or shaping of the raw material in itself is seldom a difficult or exacting task. The critical point is in stopping this process at the proper moment. The approach to this point can be watched only by some form of measurement. The most elementary method of measuring a part is to try it with the companion parts with which it is to operate. Such was common practice in the early stages of mechanical industry. This practice necessarily continues to a great extent with repair work and also in the construction of small numbers of special machines, jigs, and fixtures.

A later method consisted of measuring the parts individually, with standard measuring tools such as scales, calipers, verniers, and micrometers. In many cases, these measurements were merely preliminary to the fitting together of the parts at assembly. Fitting at assembly is expensive. It takes time and requires a relatively large amount of space and highly skilled labor. Most of the metal removed at this time is done by hand. If any great amount of metal is to be removed, the part must be taken back to the machine shop and relocated on the machine, thus interrupting other work. Under such conditions, the economic production of any great quantities of duplicate mechanisms is impossible.

Gages an Economical Necessity. Interchangeable manufacturing was developed primarily to eliminate these conditions. If parts could be made close enough to some uniform size so that

most, at least, of this fitting could be eliminated, it was evident that larger production could be secured with the expenditure of the same effort. Furthermore, many parts could be machined in advance and carried in stock, thus making earlier deliveries possible in many cases. Clearly, one of the most essential factors of such a plan is a reliable means of measuring each part as it is made. This measuring, to be effective, must insure uniformity and be economical. The use of standard measuring instruments such as micrometers is not always reliable in measuring large numbers of duplicate parts. In the first place, for many exacting conditions, measurements hurriedly made by several different men do not prove sufficiently uniform. In the second place, many of the surfaces to be measured are not readily accessible by standard measuring tools. And, in the third place, while both of the preceding conditions may often be satisfactorily met, the time consumed by this method would be too great to be economical. In order to meet all these conditions, special measuring tools known as gages have been developed.

Gages are an integral part of interchangeable manufacturing equipment. They comprise that part of the equipment the purpose of which is to measure the product, as distinguished from that part of the equipment the purpose of which is to change the form of the material or to hold the part during a manufacturing operation. Under this broad definition of a gage, it is apparent that some of the manufacturing equipment may be not only a holding device, but also a gage. In fact it is good practice to make fixtures so that an unserviceable part cannot be inserted. It often happens that when the normal manufacturing variations of certain machining processes are small and within known limits, a gage may be employed to test the size or form of the cutting tool, and not be applied directly to the product. At other times, a gage in the form of a setting block for the position of the cutting tool is made as an integral part of the fixture. Therefore, to determine the character of the gages that are required for the production of any particular part, it is necessary to consider both the requirements of the part in question and the other manufacturing equipment that is provided.

Classification of Gages According to Use. In general, there are three purposes for which gages may be needed: First, in the manufacture of large numbers of duplicate pieces, it is a measure of economy to detect and discard all unserviceable parts as soon as possible, thus saving the expenditure of additional effort on such parts. The gages provided for the purpose are commonly known as working gages. These are often limit gages, placed in the hands of the machine operator to check each individual machining operation as it is performed.

Second, it is necessary to check the parts as they are transferred from one manufacturing department to another, and also before the finished parts are sent to the stock-room or assembling floor, so as to prevent unserviceable parts from proceeding farther. It is also customary to inspect the parts in process after certain groups of operations have been performed. The gages used for these purposes are commonly known as inspection gages. Some of these are limit gages which are often duplicates of some of the working gages, while others are functional gages which check the results of several operations at one time. These inspection gages are generally used by a force of inspectors who are independent of the production department.

Third, when gages are used to any extent, it is necessary to have reliable standards as a means of checking the working and inspection gages and to establish the sizes of new gages as the old ones wear out. Such standards are variously known as checks, reference gages, standards, master gages, and model parts. These gages are usually kept in the tool-room or in the hands of a gage inspector, and their purpose is to test the working and inspection gages so as to insure a suitable degree of precision in them.

Required Accuracy of Gages. Extreme refinement in gages is expensive and is unwarranted by the functioning of the majority of component parts. The accuracy required by a gage depends in a great measure upon the extent of the manufacturing tolerances. If these tolerances have been properly established, only a small percentage of them will be exacting. It is evident that a gage used to measure a dimension which has a tolerance

of 0.002 inch must be made closer to size than one which measures a dimension having a tolerance of 0.020 inch. It is common practice to establish the tolerance on a gage at 10 per cent of the component tolerance. A tolerance of less than 0.0002 inch should seldom be specified unless the conditions are unusually exacting and economy is no object.

With variations in gages, no matter how slight, and with parts passing through successive inspections, many misunderstandings are inevitable unless precautions are taken to guard against them. The most common method of meeting this con-

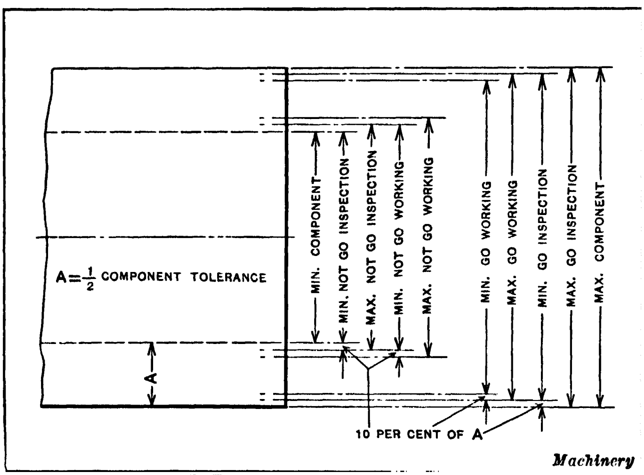


Fig. 1. Diagrammatic Illustration showing Differences between Working and Inspection Gages and Tolerances on these Gages

dition is to establish the limits of the working gages inside the limits of the inspection gages. Fig. 1 is a diagrammatical illustration showing the differences between working and inspection gages and the tolerance on these gages. The full lines represent the maximum size of a part while the dotted lines represent the minimum size. The maximum size of the "go" inspection gage is identical with the maximum size of the component. The minimum size of the "go" inspection gage is 10 per cent of the component tolerance smaller than its maximum size. The maximum size of the "go" working gage is identical

with the minimum size of the "go" inspection gage, while its minimum size is 10 per cent of the compónent tolerance smaller. In a similar manner, the minimum size of the "not go" inspection gage is identical with the minimum size of the component while its maximum size is 10 per cent of the component tolerance larger. The minimum size of the "not go" working gage is identical with the maximum size of the "not go" inspection gage, while its maximum size is 10 per cent of the component tolerance larger. As the tolerance on the component increases, it is often advisable to reduce this percentage. Thus, for plain plug and snap gages a tolerance greater than from 0.001 to 0.002 inch is seldom necessary.

Relation between Working and Inspection Gages. It is evident that if the sizes of the working gages are always kept inside of the sizes of the inspection gages, few questions should arise due to parts passing the working gages and being rejected by the inspection gages. This arrangement may be secured by making and maintaining the gages as outlined in the foregoing or by a process of selection and grading. If all the gages used at the same time for the same surface are checked concurrently, those permitting the widest variation in the product should be used as inspection gages, while the others should be used as working gages. In all cases the nominal sizes of the inspection limit gages should be identical with the limits of the component, and all tolerances should keep them within the limits of the component. Thus, the maximum gage may be smaller than its nominal size but never larger, while the minimum gage may be larger but never smaller.

Such a practice brings up two age-old arguments: First, that a 1-inch plug will not enter a 1-inch hole, and second, that the tolerances on the gages rob the manufacturer of some of the tolerances given on the drawing. The answer to these arguments depends upon the interpretation of the drawing. If this interpretation is that the dimensions and tolerances given on the drawing represent the extreme sizes of the limit gages, and all variations of whatever source must come within these limits, neither of the above arguments has any weight; and this is the

only logical interpretation that can be used definitely and consistently. With this interpretation, it does not matter whether the hole is ever exactly one inch or not. As for the second argument, if the shop does not attempt to maintain its product within slightly smaller tolerances than the extreme tolerances, too large a percentage of parts will inevitably run outside of the tolerances and be rejected.

Gage Requirements Controlled by Ultimate Economy. A limit gage is one that measures both the maximum and minimum sizes of the component. Such gages usually check elementary surfaces, although they are at times provided for checking profiles and other composite surfaces. The most common types of limit gages are snap gages, plug gages, ring gages, depth gages, and length gages. A functional gage is one that checks primarily the functional operation of a component without strict adherence to its exact physical dimensions. Several types of these gages were discussed in Chapter V. The purpose of such a gage is to insure, as far as possible, the proper assembling and operation of all parts.

The extent to which gages should be employed depends on the product and the rate of production. If the rate of production is low, it is often possible to control the accuracy of the product with standard measuring instruments. As it increases, the time spent in using standard instruments reaches a point where the time saved by the use of gages more than pays for their cost. Gages should be provided for only those surfaces which it is essential to maintain within certain dimensions. Each gage should have its definite purpose just as any other piece of manufacturing equipment has some definite duty to perform. A gage is a preventive and not a cure. Gages are required wherever their use will tend to prevent the production of faulty work. Thus a more complete system of gages is necessary in a shop that employs a large percentage of semi-skilled labor than in a shop employing highly skilled operatives.

Interchangeability between Parts Made in Different Shops. Experience has shown it to be difficult to obtain interchangeable parts from several independent plants producing a common

product unless great precaution is taken at the outset to insure this result. Under these conditions the most certain method is to maintain identical working and gaging points at the various plants for all functional surfaces. Component drawings, properly dimensioned, assist greatly in accomplishing this end. This does not necessarily mean that the design of the gages must be identical. The exact design of a gage is never in itself a matter of great importance. The effectiveness and economy of the results obtained are the important considerations. Usually the gaging equipment must be very complete to meet successfully the requirements of interchangeability between independent plants.

For the further discussion of gages, they will be classified according to their type, such as snap gages, ring gages, plug gages, profile gages, thread gages, flush-pin gages, functional gages, etc.

Snap Gages. Gages were first developed as part of the equipment necessary for manufacturing large numbers of duplicate parts. Now gages are used to a large extent in the production of smaller numbers of parts. In this case, however, many modifications in the design, such as adjustable features, have been developed to keep the cost within reasonable limits. Snap gages for use in the manufacture of large numbers of interchangeable parts will be discussed first. The earliest form of snap gage was the "one-size" type; that is, a gage to measure one flat dimension only. This type is still used to a large extent in toolrooms and machine shops when limits are not expressed on the drawings and when the clearances for the different fits are left to the judgment of the workmen.

The limit gage with two steps was later developed, one step being provided for measuring the maximum limit, and the other for measuring the minimum limit. For small parts produced in large quantities the non-adjustable gages are most satisfactory. Formerly a number of gage slots were cut in one piece of steel to permit a combination of gages in one piece, but the disadvantage of this design was that when one gage became worn the whole gage was lost. One method of overcoming this disadvantage is

to have a filler block inserted on one side of the gage jaw which can be replaced when the gage becomes worn. Sometimes a combination of gages is mounted on a ring similar to a key ring. In a later snap gage construction, individual gages are assembled in convenient units and held together by clamping strips and screws. This construction permits the easy removal of a gage when necessary.

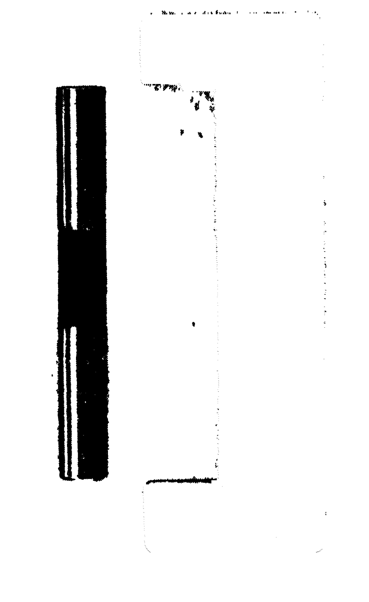


Fig. 2. Snap Gage with Shallow Throat for measuring Lengths

Various Other Types of Snap Gages. One type of snap gage has an intermediate step between the two limit steps, to aid the machine operator in setting up and adjusting the tools. In setting up a machine for repetition work, the object is to set the tools so as to have the maximum time between adjustments. When a circular part is machined with a form tool or a box-tool, the piece becomes larger as the tool wears. Therefore, the initial setting should be as near the minimum or "not go" limit as other conditions will permit. The intermediate steps on these working snap gages is made to approximately the mean dimension. Thus, if the operator sets the machine to produce work between the minimum limit of the gage and the intermediate step, the life of the tool, as regards wear at the particular setting, is equal to at least half of the working tolerance. These intermediate steps are not used on inspection gages, as they would serve no purpose there.

There are two general types of snap gages, those with deep throats for measuring diameters and those with shallow throats as illustrated in Fig 2, for measuring lengths. When the gage

slot is very narrow, snap gages are frequently made with a removable strip serving as one side of the gage slot This construction permits the gaging surfaces to be readily ground

For larger pieces and for smaller rates of production, adjustable snap gages have been developed Gages of this type are shown in Fig 3. In common with other types of adjustable tools, these should be adjustable in the tool-room and fixed in the manufacturing departments This result is obtained by providing a place for a seal which must be broken before the gage

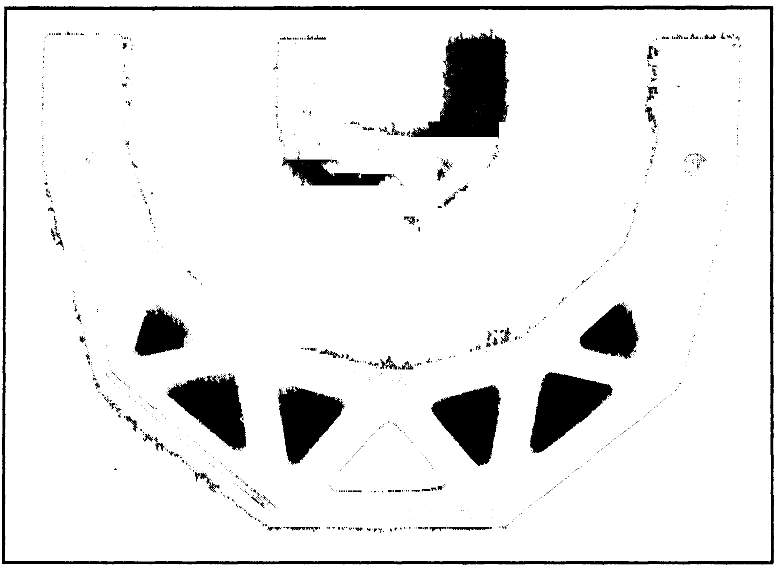


Fig 3 Adjustable Snap Gages employed for Comparatively Large Pieces or when the Rate of Production is Small

can be adjusted, thus preventing the adjustment from being tampered with. These gages may be readily adjusted in the toolroom to any desired limits, so that a few sets of them provide a flexible and economical equipment of gages for checking elementary dimensions, such as external diameters, thicknesses, and lengths.

Ring Gages. Under some conditions, the use of a snap gage for testing diameters is not sufficient, and in such cases ring gages are employed. Wherever possible, however, snap gages

should be employed, as they are more economical to use. A snap gage can be used more rapidly than a ring gage. Furthermore, on many parts, a machine operator cannot use a ring gage without removing the work from the machine. The extent of the tolerance required to manufacture a part economically depends in a large measure on the type of gage employed. For example, if a ring gage is used in place of a snap gage, any departure from rotundity or from size affects the acceptance of the part by the gage. Thus, in effect, a snap gage checks an elementary surface while a ring gage checks a composite one.



Fig. 4. A Ring Gage of the Ordinary Type

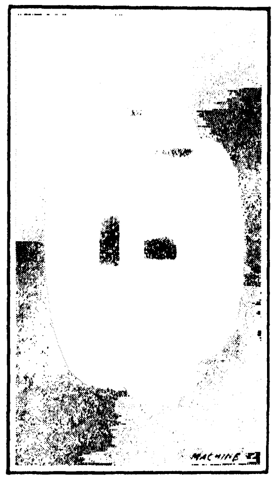


Fig. 5. Counterbore Plug Gage

The severest possible inspection of a cylindrical surface is obtained by the use of "go" ring gages and "not go" snap gages. It is therefore evident that a description of the gaging and inspection methods is essential in the specifications to avoid misunderstandings. The larger ring gages are made as individual gages, as shown in Fig. 4, and are sometimes provided with handles. Several small ring gages are often inserted into a soft holder which keeps them together.

Plug Gages. Plain plug gages are old and simple forms. Standard plug gages, as with standard snap gages, are largely

used in tool-rooms and general machine shops. A "not go" gage was a later development and is attached either to the other end of the same handle as the "go" gage or is a separate gage. It is common practice to make standard handles and standard plug gage blanks, later finishing these blanks to the size required and assembling them into the standard handles. Solid double-ended plug gages are open to the same objections as solid combined snap gages. If one end becomes unserviceable, the whole gage must often be discarded. In standard limit plug gages the minimum or "go" ends are made longer than the maximum

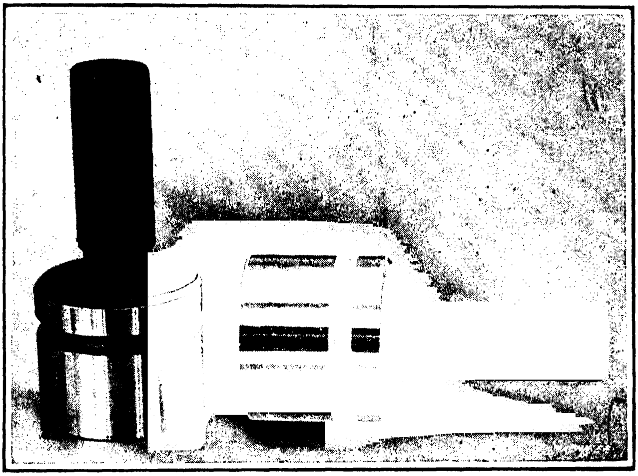


Fig. 6. Two-step Plug Gages used for the Inspection of Through Holes

or "not go" ends; this practice is followed in order to make the "go" end readily distinguishable from the "not go" end, and, furthermore, as the "not go" end is subject to little wear, there is no necessity for making it very long.

When a through hole is to be gaged, it is customary to make a two-step plug gage such as shown in Fig. 6. This permits rapid inspection, but the gage cost is greater than when two separate ends are used. Often, however, the saving in inspection costs will greatly exceed the additional expense of this type of gage, so that the practice is economical in the long run.

The Pratt & Whitney Co. manufactures a gage known as the "star" gage, which is of the expansion type, having four movable measuring ends. This gage is used for measuring the bores of tubes and jackets for large guns, the bores of engine cylinders, etc. Plug gages made from flat stock are often used to measure the width or length of slots or grooves. These gages are frequently rounded at the end and used for measuring the length of a splined slot.

Plug Gages for Several Surfaces and Taper Surfaces. Thus far only gages for elementary surfaces have been considered.

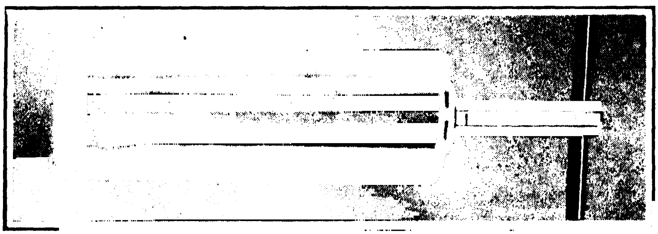


Fig. 7. Taper Plug Gage

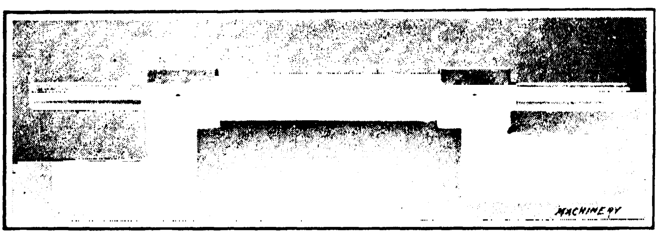


Fig. 8. Combination Plug and Snap Gage

The dimensions for such gages are readily determined from the limits expressed on the component drawings. To test concentricity, however, the assembly requirements of the mating parts must be considered. A gage of this type for testing the concentricity of the bore and counterbore of the main bearing of an automobile transmission case is shown in Fig. 5. Plug gages are often made with steps on the end to gage both the diameter and the depth of a hole at the same time. At other times a sliding collar is provided which saves the use of a straightedge if the hole to be gaged is either countersunk or counterbored.

Taper plug gages are usually provided with either lines or steps to gage not only the diameters of the tapered hole, but also their locations. A taper gage is shown in Fig. 7. A groove is cut near the large end of this gage and the width of this groove indicates the limits. The gage must go into the work until one edge of the groove is flush with or below the face of the part, while the other edge must never go in beyond the face of the part. Sometimes steps are provided to indicate the limits and at other times, lines are graved to serve the same purpose. If the tapered hole is properly dimensioned on the component drawing so

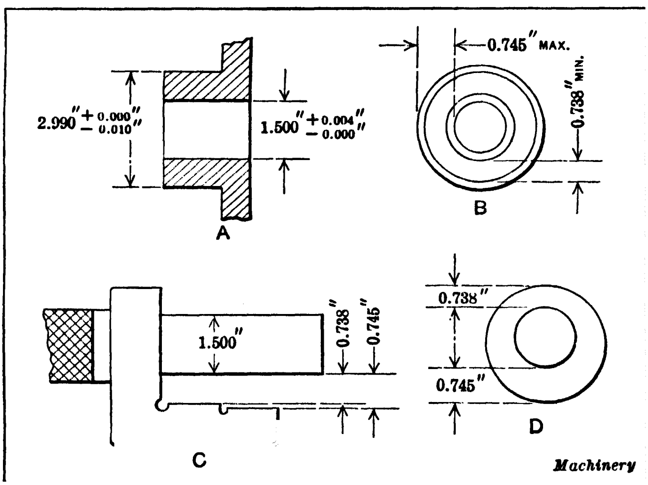


Fig. 9. Illustration showing how Compound Tolerances are involved when testing the Concentricity of a Hub with a Hole

that no compound tolerances exist, the correct dimensions of the gage are readily determined. If compound tolerances exist on the drawing, however, some arbitrary method of interpretation must be promulgated as otherwise endless arguments will ensue about the proper gage sizes.

Application of Combination Plug and Snap Gages. A combination plug and snap gage is illustrated in Fig. 8. Such gages may be required for several purposes. They may be used to test the concentricity of a hub with a hole, the location of a hole from the edge of a part, the depth of a slot in relation to a hole,

etc. In determining the dimensions of such gages, compound tolerances are almost inevitably present. Therefore, some arbitrary method of interpreting the drawing must be established. A gage for testing the concentricity of the hub with a hole will be considered first.

Assume that the hub and hole represented at *A* in Fig. 9 must be gaged. The diameter of the plug in this case will be taken as the minimum size of the hole or 1.500 inches. If it is considered that the limits given for the hole and hub establish parallel zones of permissible variations, as shown at *B*, there will be a

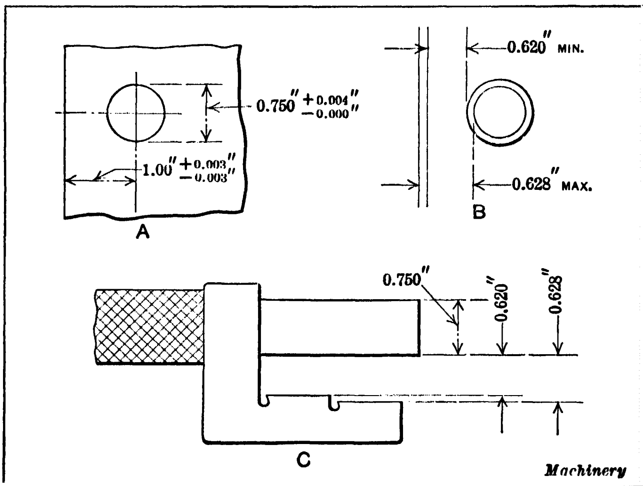


Fig. 10. Application of a Combination Plug and Snap Gage in testing the Location of a Hole from the Edge of a Part

minimum distance of 0.738 inch between the gaging parts of the combination gage shown at *C*, and a maximum distance of 0.745 inch. The use of this gage will then permit the extreme condition of eccentricity which is shown at *D*. If the diameter of the hole is maximum and the eccentricity is at this extreme, the size of the hub will be 2.987 inches. If the diameter of the hole is minimum, the size of the hub will be 2.983 inches. The more nearly concentric the hole and hub are maintained, the greater the amount of tolerance which remains for their diameters. The full tolerance on these diameters becomes available only when

they are concentric with each other. It may be pointed out that the condition shown at *D* does not keep the parts within the parallel zones shown at *B*. This is true, and will be found to be true wherever compound tolerances are involved. It is this condition that makes it necessary to establish some arbitrary interpretation of the drawings.

The next example will be of a combination plug and snap gage used to test the location of a hole from the edge of a part. The procedure to determine the gage sizes is identical with the foregoing. A part having a hole which is to be gaged from an

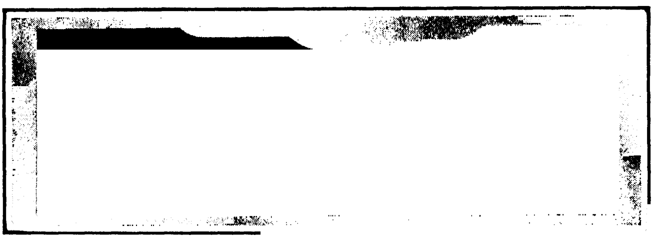


Fig 11. Simple Type of Contour Gage for checking the Uniformity of Contours or Profiles

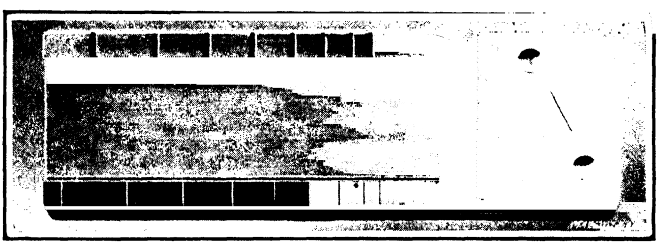


Fig. 12. Matching Gage used in testing the Positions of Graduations on a Part

edge is shown at *A*, in Fig. 10. The parallel zones of variation given on the drawing are shown at *B*, and the gage is shown at *C*. The diameter of the plug is shown as the minimum size of the hole. As a matter of fact, the diameter of the plug may be any size smaller than the hole in these cases, as the gaging dimension is controlled by the gap between the edge of the plug and the steps of the arm. A plug of minimum size is generally used so that it may also be employed as the "go" gage for the hole.

A modification of this gage is used to test the position of a hole that must be carefully located between two edges. One side of the snap gage part is made longer than the other to detect the side at fault in case the gage does not go on.

Contour or Profile Gages. Contours or profiles are among the most difficult surfaces to gage properly. A contour gage of the earliest type is shown in Fig. 11, but this type should be used only when accuracy is not important. The main objection to this form is that it measures only the shape of the work and not the

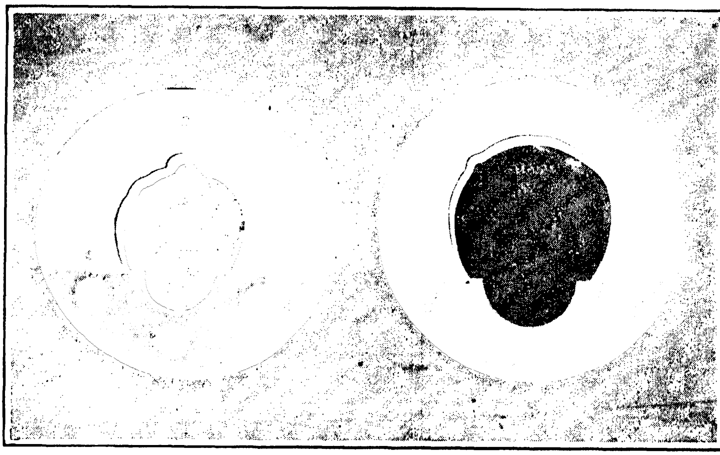


Fig. 13. Receiving Gages having Holes or Openings Corresponding to the Shape of the Part inspected by them

location of the contour. A gage designed to overcome this objection has guides for the contour and locating points for the work.

Contour gages of the matching type are sometimes used when great accuracy is not required. The part is placed on the gage and its outline compared, either visually or by a straightedge, with the outline of the gage. In Fig. 12 is shown one type of matching gage. This is used to test the position of graduations on a part. The work is inserted in the gage and the graduations are compared visually. Similar gages are often used for checking the shape of springs made from flat stock and also for checking the graduations on dials, etc.

Receiving Gages. The simplest form of receiving gage is a flat templet in which a hole or opening is cut corresponding to the form of the part to be inspected. Such gages do little more than insure interchangeability. If the part enters, it is not too large, but it is impossible to determine from such a gage if the piece is too small. If the piece does not enter, it is too large. It is difficult to find the exact location and amount of the error. Gages of this type are shown in Fig. 13. In an improved type

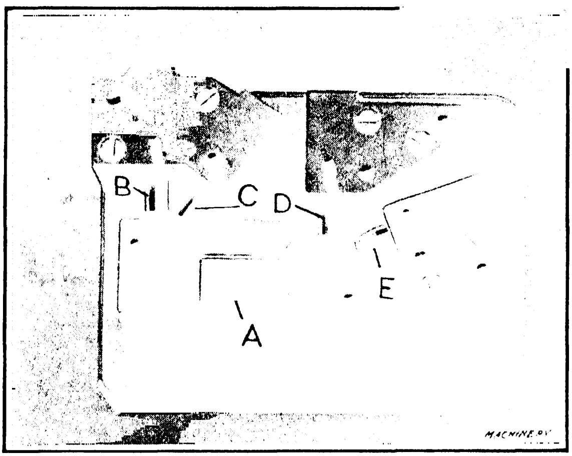


Fig. 14. Profile Gage which checks the Contour of the Work by Flush Pins

of receiving gage the work is inserted in the opening of the gage and properly located there. This opening is a uniform distance from the work so that maximum and minimum plug gages may be inserted between the work and the gaging surfaces.

This same principle may be applied to the gaging of irregular openings by making a male profile a uniform amount under size and using limit plug gages to check for errors. Fig. 14 shows another type of profile gage which checks the contour to definite limits. In this case the contour consists of several flat surfaces cut at different angles. The part is located by block *A*. The flush pins *B*, *C*, *D*, and *E* check the various faces on the piece.

Dial Indicator Contour Gages. The highest development in gages for formed surfaces is doubtless the dial indicator contour

gage, a simple example of which is shown in Fig. 15. This type of gage consists of a baseplate which has mounted on it means for holding the piece to be gaged as well as the master form with

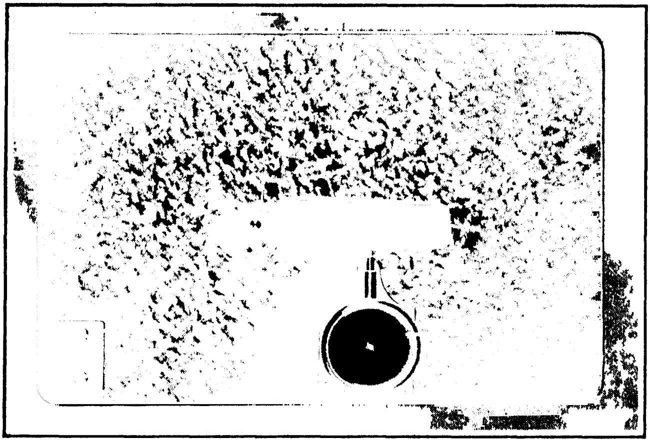


Fig. 15. Dial Indicator Contour Gage

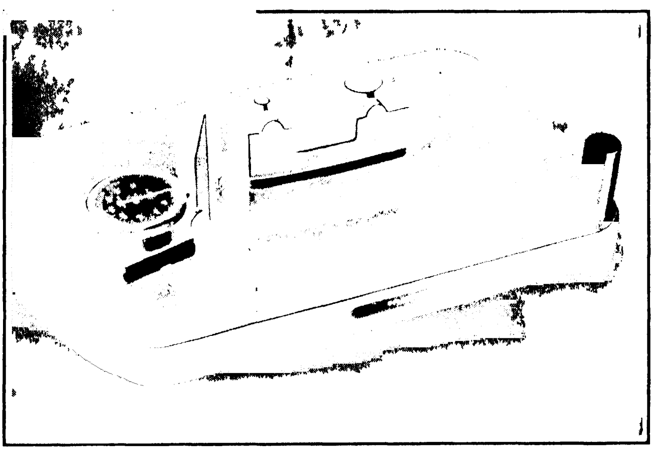


Fig. 16. Another Type of Dial Indicator Contour Gage

which the piece being gaged is compared. The piece to be gaged is shown in position at *A*, and the master form is directly beneath it. The stud *B* is used to locate the work. The dial indicator *C* is mounted on a baseplate of its own and slides on the baseplate

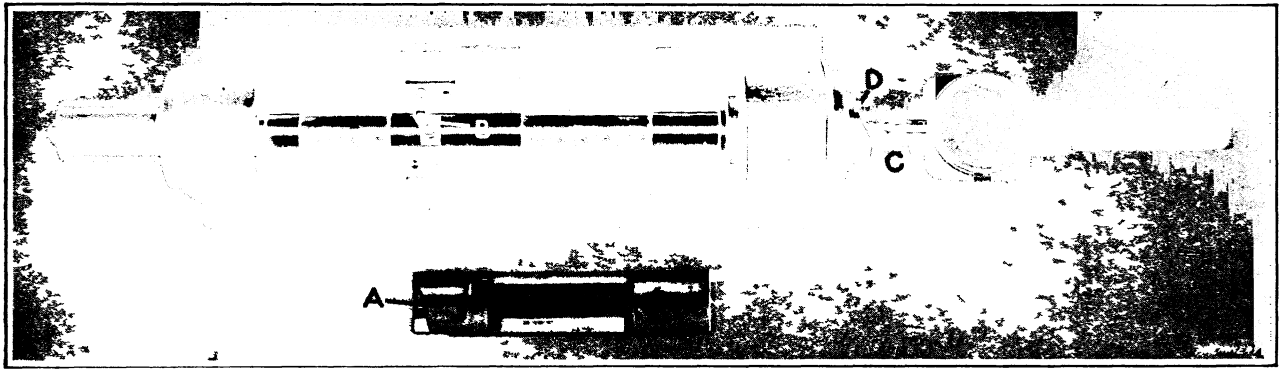


Fig. 17. Application of the Dial Indicator Contour Gage in inspecting the Cam Surface of a Part

of the gage The point on the baseplate of the indicator is brought in contact with the master form, while the point of the indicator itself is in contact with the piece to be gaged. The amount and direction of the tolerance is stamped on the face of the gage baseplate At *D* is shown a setting block which is used to set the indicator to zero

This type of gage makes it possible to determine quickly and accurately whether the work is within the prescribed limits. The tolerances on the work may be varied along the contour, and the indicator will show the variations at any point The wear on these gages is almost negligible, as the master form is in contact only with the small hardened point of the block on which the dial is mounted These gages are convenient for gaging slots having irregular bottoms

Sometimes these gages are made so that the point

of the dial indicator follows around the master form, while a projection on the baseplate registers against the work. Such a gage is shown in Fig. 16. Otherwise its operation is the same as in the previous example. This type of gage lends itself readily to the inspection of work having many difficult and exacting requirements. A modification is shown in Fig. 17. The piece to be gaged is shown below the gaging fixture. This gage is used for inspecting the cam surface, *A*. In operation, the pin *B* follows the cam surface *A*, while the point *C* on the dial indicator follows the master cam *D*. Any variations are thus readily and accurately detected. This type of gage is not limited to the gaging of contours, but may also be used for testing depths, steps, recesses, etc., much more readily than a great number of snap, plug and depth gages.

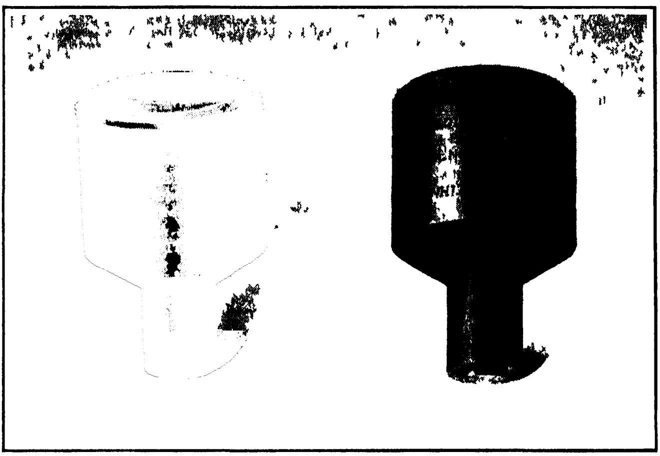


Fig. 18. Simple Form of Flush-pin Gage, consisting of a Plunger which slides in a Sleeve

Flush-pin Gages. Flush-pin gages are generally used for tolerances over 0.002 inch, especially in cases where snap gages cannot be applied conveniently. It is possible to use them for smaller tolerances, but it is seldom practicable in such cases to depend on the sense of touch. The flush-pin gage in its simplest form, as shown in Fig. 18, consists of a plunger which slides in a sleeve. Steps are provided, sometimes on the top of the plunger

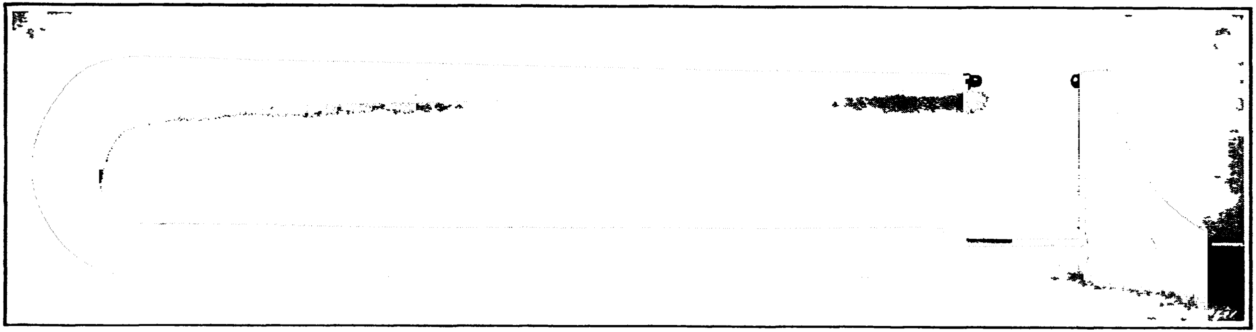


Fig. 19. Sliding-bar Gage used in testing the Thickness of the Bottom of a Shell

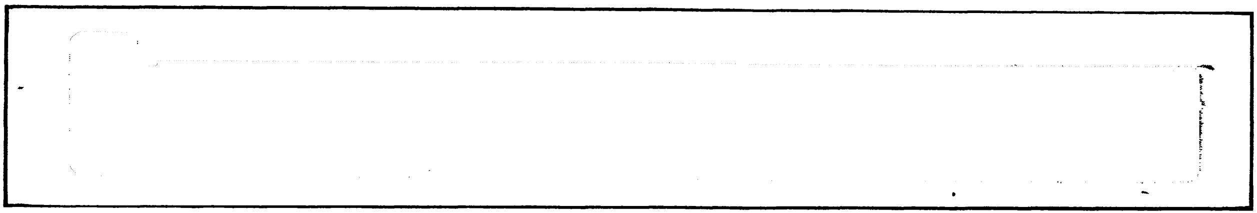


Fig. 20. Gage used for measuring Lengths, the Limits of the Work being indicated by Scribed Lines at the Right-hand End

and other times on the sleeve, which agree with the specified tolerances. The dimension to be gaged is represented by the projection of the plunger beyond the bottom of the sleeve. The same principle may

be applied in a great variety of ways. Fig. 14 shows its application to a contour gage.

The advantages of flush-pin gages may be briefly summarized as follows: The flush-pin gage is the simplest form of gage for measuring the position of one surface with reference to a locating point, when the relation is such that a snap gage cannot be used. Flush-pin gages are subject to a comparatively small amount of wear, and repairs are simple. Mistakes in reading the indications on them are rare.

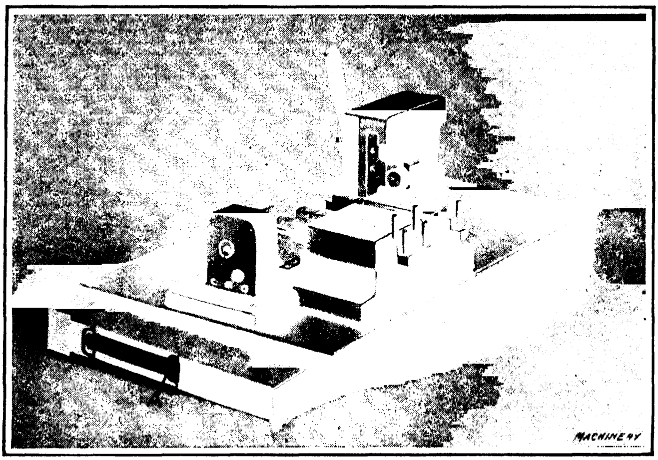


Fig. 21. Gages with Three Sets of Double Flush Pins

Sliding-bar Gages. Among the gages made with sliding members, the sliding bar gages occupy an important place. In principle, they are similar to flush-pin gages, but differ in the method of taking the readings or indications. A common type is similar to a micrometer in general construction. On the sliding bar is engraved a line, which must be between two steps on the frame if the part being measured is acceptable. Another similar example is shown in Fig. 19. Two lines are engraved on the cylindrical part of the frame, while a single line is engraved on the slotted surface of the sliding arm. The arm swings out of the way to allow the gage to enter the work. This gage is used to measure the thickness of the bottom of a shell, and is made light

for ease of operation, as the work itself is too heavy to be handled rapidly.

Fig. 21 shows a gage with three sets of double flush pins for measuring the irregular slot in the piece shown in *A*. On sliding-bar gages where the tolerance is too small to be read from lines engraved on the plunger, the movement of the bar is multiplied by a lever which points to a graduated scale on the side of the gage. In this way it is possible to note quickly whether the work is machined within the requirements or not.

Flat Depth and Length Gages. A simple type of templet gage to measure the depth of a counterbored hole is shown in Fig. 22.

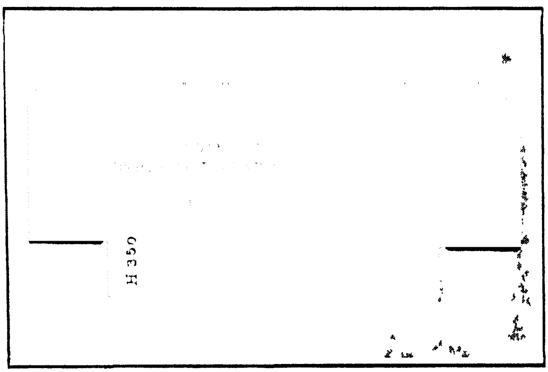


Fig. 22. Simple Type of Templet Gage

One step is used as a "go" gage, while the other is used as a "not go" gage. A similar gage can be used for measuring the length of a shoulder. Fig. 20 illustrates a length gage, on which the limits are indicated by scribed lines. This type is really a special scale for measuring certain fixed dimensions.

Hole gages. A "hole gage" is a gage for testing the location of holes relative to each other or to a specified register point. The gages measure the distances between the outer and inner points of the peripheries of the holes. They are, in effect, functional gages. While the gage does not actually measure the center distances, it will insure that the accepted parts may be assembled properly. When designing such gages, the functional conditions of the mating parts must be carefully checked and

analyzed to insure that the results desired will be secured without imposing unnecessary hardships on the manufacturing departments. Attention is called to the previous discussion of these conditions in the paragraph "Dimensioning of Holes" in Chapter V.

This type of gage comprises an almost infinite number of designs. Some may be simple templets with studs or bushings and plugs, while others may be almost duplicates of the drill jigs used in producing the holes, using plugs through the bushings instead of drills and reamers. In fact, if the drill jig is not

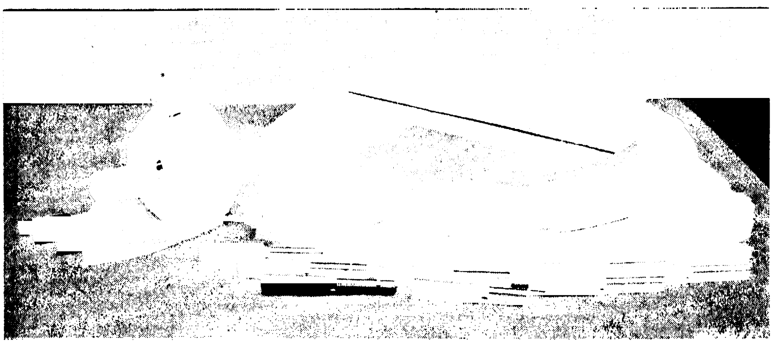


Fig. 23. Hole Gages and Plugs used in testing the Locations of Holes in an Automobile Transmission Case

in constant use, and is kept properly checked, the addition of suitable plugs will make it an extremely effective gage. A few examples of gages of this type will be illustrated to indicate their wide variety. In Fig. 23 are shown two hole gages with their plugs. These are used for testing the locations of the holes in the end of the transmission case dealt with in Chapter VIII. They are examples of the simplest type of hole gages.

A more elaborate gage for the same transmission case is shown in Fig. 24. The holes in the shifter cover face of the work are tested with this gage for their relation to each other and to the main shaft. The transmission case is centered on the arbor and clamped by the hollow plug *A*. The stud *B* locates the case radially. The plate *C* is placed on the shifter cover face, and is

located from the central arbor by forks *D* on the plate fitting in the grooves *E* on the arbor. The small plug *F* is then used to test the locations of the six small holes in the shifter cover face.

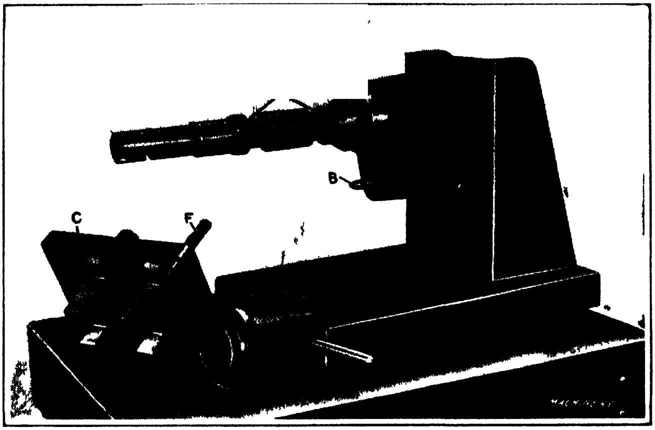


Fig. 24. Gage used in testing Holes in a Transmission Case, the Work being mounted on the Arbor for the Purpose

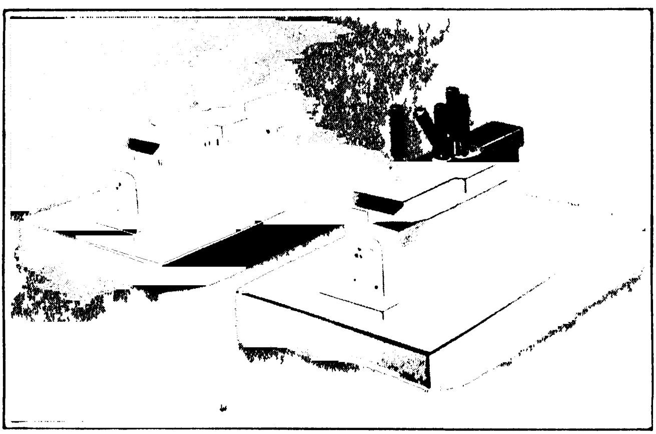


Fig 25. Another Type of Hole Gage which is a Duplicate of the Drill Jig used in machining the Holes in the Work

At the left in Fig. 25 is shown a hole gage unloaded, and at the right, the same gage is shown with the work in the gaging position. This gage is a duplicate, in its general design, of the jig that is used when drilling the holes in the shifter cover face.

Factors Involved in Gaging Threads. At the present time, a wide difference of opinion exists as to the proper method of testing threads. Owing to the fact that a thread is a complicated composite surface, and that any composite surface is difficult to measure readily, and also because threads are employed in so many places for a wide variety of purposes, this condition is one to be expected. There are three main elements in a threaded surface: The form of the thread, the lead or pitch of the thread,

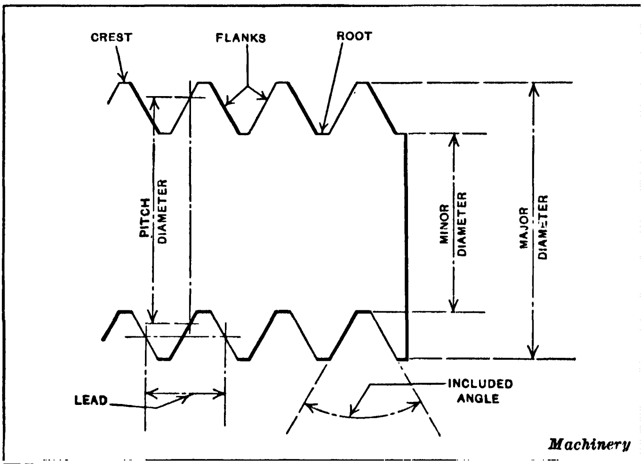


Fig. 26. Diagram illustrating the Meaning of the Terms used in the Discussion on Thread Gages

and its diameter. The form of the thread itself is composed of several surfaces. The form of a sharp V-thread is composed of two angular flanks, but this form is theoretical only. A certain amount of rounding or flattening is inevitable at the crest and root. The form of most other standard threads is composed of four surfaces — the crest, the root, and the two flanks. Thus a thread is a composite surface, the accuracy of which depends upon the interrelation of the following: The diameters and form of the crest and root, the form of the two flanks, and the lead.

There is a broad general principle in regard to limit gages which should always be kept in mind. Where compound tolerances are not involved, a "go" gage with fixed measuring surfaces may check as many dimensions at one time as desired,

and effective inspection will be secured. On the other hand, an effective "not go" gage can check only one dimension. By effective inspection is meant assurance that specified requirements in regard to size are not exceeded. The above principle must be applied with common sense, as there are a great many requirements that drawings fail to express clearly. This is especially true in the case of surfaces that are threaded.

The gaging of an externally threaded component will now be considered. A diagram of such a surface, illustrating the terms that will be used in the discussion, is shown in Fig. 26. The outside, or largest diameter, will be called the "major diameter." The smallest diameter will be called the "minor diameter." The top of the thread will be called the "crest," and the bottom, the "root." The sides of the thread will be called the "flanks." The dimension taken square with the axis of the thread from flank to flank at any point, will be called the "pitch diameter." The "included angle" is the angle between the flanks of two threads, and the "lead" is the distance from a certain point on one thread to a similar point on the next thread.

Method of Expressing Tolerances on Threaded Parts. The correct method of gaging this thread consistently depends on the manner in which the tolerances are expressed. In any event, the major and minor diameters should be treated as independent elementary surfaces. They may be gaged, when necessary, either independently or in conjunction with the other elements on the "go" gage. The tolerances on the other elements may be expressed in one of two ways — either as a total cumulative error expressed in terms of the pitch diameter, which will eliminate compound tolerances, or as individual tolerances on each element, which will introduce compound tolerances with all their resulting annoyances and inconsistencies.

If the tolerances are expressed in the second manner, the only consistent method of gaging would be to provide suitable gages for each element and to test each of them independently. Any gage to test all of the elements at one time would need to be a functional gage and its design would involve a careful study of each set of companion threads to establish the proper dimen-

sions. If the tolerances are expressed in the first manner, the gaging problem is simpler. The "go" gage may be a ring thread gage checking the "go" dimensions of all elements. As a matter of economy, in making the gages, it is necessary to provide clearance at that part of the ring gage which would check the major diameter, so as to facilitate lapping or grinding. This dimension on the part may readily be checked, when desired, by a simple snap or ring gage.

A decided difference of opinion exists as to the proper length of engagement for thread gages. From an academic viewpoint,

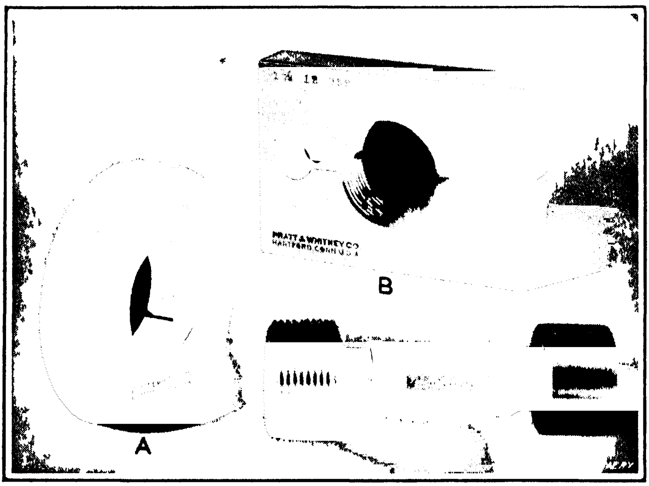


Fig. 27. Standard Ring Thread Gages and a Standard Plug Thread Gage

the gage should be as long as the effective length of the thread on the component. The effect of the use of longer or shorter gages is to hold the error in the lead of the thread to a lesser or greater amount. Many conditions exist where a relatively large error in lead is not important. In such cases, a shorter gage will make the manufacturing conditions much easier, and at the same time pass only satisfactory parts to meet such conditions. For example, if the length of a gage is reduced to one-half the effective length of the thread on the component, it will permit an error in lead of double the amount which would be

allowed by a gage which is as long as the full effective length of the thread on the component.

Theoretically, individual "not go" gages should be provided for the major diameter, minor diameter, and pitch diameter. Practically, the most severe requirements will usually be met by providing a "not go" gage for the pitch diameter only. This would be a ring thread gage, made to clear both the major and minor diameters of the component. Its length must be such that it will not engage over one or two turns on the component. As a matter of fact, the strength of the engagement of a screw and nut depends primarily on the amount of the engagement area between the threads.

In many cases suitable inspection will be secured by the use of a "go" ring thread gage which has clearance at the major diameter of the component, and a "not go" ring or snap gage for the major diameters of the component. At *A* in Fig. 27 is shown a standard ring thread gage. The gaging of internally threaded components involves the same problem as the gaging of those threaded externally. A standard plug thread gage for this purpose is shown at *C*. In this case the "go" gages are made to clear the minor diameter of the component, while the "not go" gages are made to clear both the major and minor diameters.

Types of Thread Gages. Standard plug and ring pipe thread gages are tapered, and on this account one gage acts both as a "go" and as a "not go" gage. A notch on the gage must be flush with the end of the part within a specified number of turns. These gages are made to clear both the major and minor diameters. In Fig. 28 is shown a "qualifying" gage for the breech mechanism of a large gun. This is a case where the thread must start in a certain specified position. A line is graved on the flange of this gage which must coincide within specified limits, when the gage is screwed home, with another line on the work. The gage measures the relationship between flanks on the work and surface *A* on the gage. This gage is cleared at all points except at surface *A* and on the thread flanks, the angle of the threads being sufficient to center the gage when it is screwed home.

Wing and Indicator Gages. Wing gages are used in some instances where snap gages cannot be conveniently employed. These gages are of the limit type and have two projections or wings. The principle is that one wing must pass the surface of the work to be gaged, while the other must not. This construction permits work to be rapidly and accurately gaged.

Many effective gages can be made simply by providing suitable stands or holding blocks for dial indicators. In one of the prominent watch factories, a large percentage of the gaging

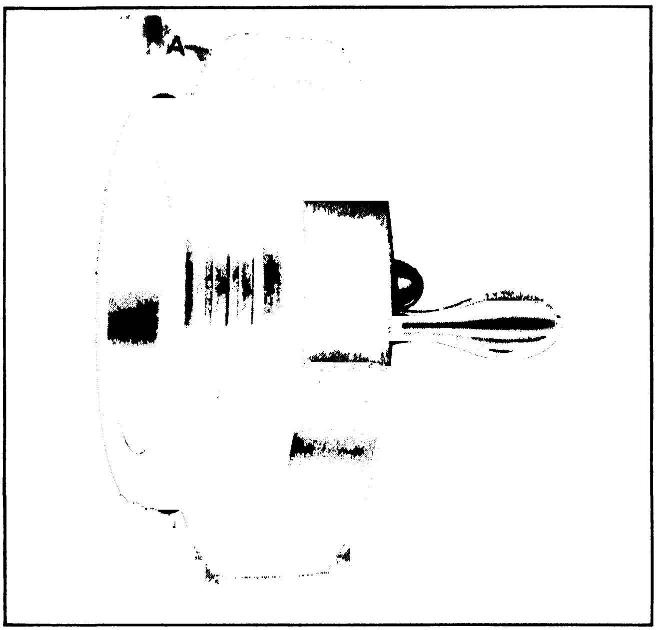


Fig. 28. Qualifying Gage for inspecting the Breech Mechanism of a Large Gun

equipment is constructed in this manner. These indicators can be set up not only to measure lengths, diameters, etc., but also profiles and locations. Several standard indicating gages are now on the market which require very little in the way of holding blocks, etc., to adapt them to measure a great variety of surfaces. In Fig. 29 is shown an amplifying gage, which is very

rapid in operation. In Fig. 30 is shown an indicator used in connection with bench centers for the purpose of testing the concentricity of a rifle barrel that is assembled with a receiver.

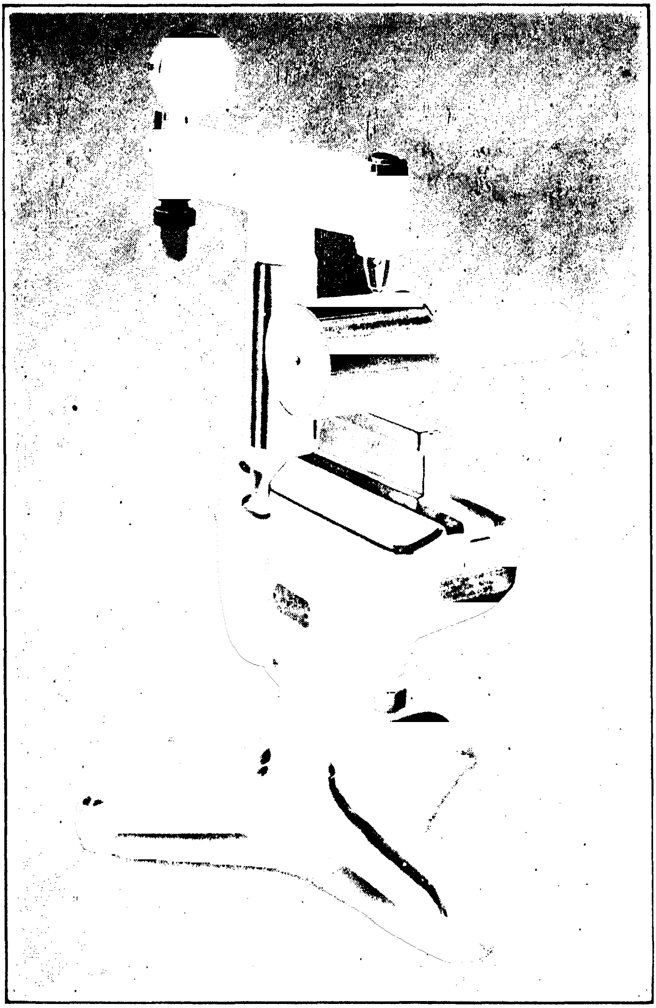


Fig. 29. Amplifying Gage which permits the Rapid Inspection of a Large Variety of Surfaces

Functional Gages. A functional gage is one that tests the functional operation of a component without strict adherence

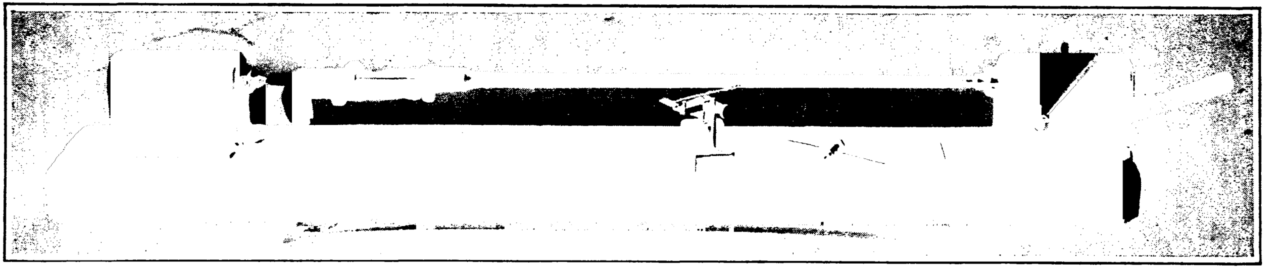


Fig. 30. Indicator set on Bench Centers for testing the Concentricity of a Rifle Barrel

to its exact physical dimensions. Thus, when a repair part is made for a mechanism and fitted to the machine, the machine itself becomes a functional gage for that part. In manufacturing, there are often parts or surfaces on some components which cannot be checked satisfactorily by a series of individual measurements. As a final test for these parts, functional gages are of great value. In some cases, it is possible to eliminate several individual gages, at least for inspection purposes, by the use of suitable functional gages. These duplicate as far as possible the functional conditions required by the mechanism. In fact, in many cases they are almost duplicates of the mechanism itself.

For large work and relatively small rates of production where ordinary gages would be heavy and cumbersome and the number required for effective inspection would be large, the functional gage offers a satisfactory means of gaging. Sometimes, of course, modifications of the design of the mechanism must be made in the functional gages to permit them to be assembled and disassembled readily. In general, they duplicate as far as possible the functional conditions required by the mechanism.

Functional Gaging of Gears. The satisfactory gaging of gear teeth is a complicated and difficult problem, if each element is tested independently, because of the many factors involved. If the testing is reduced to a functional inspection, however, the problem becomes simpler. The prime object of gears is to transmit a uniform motion, and if this result is accomplished it does

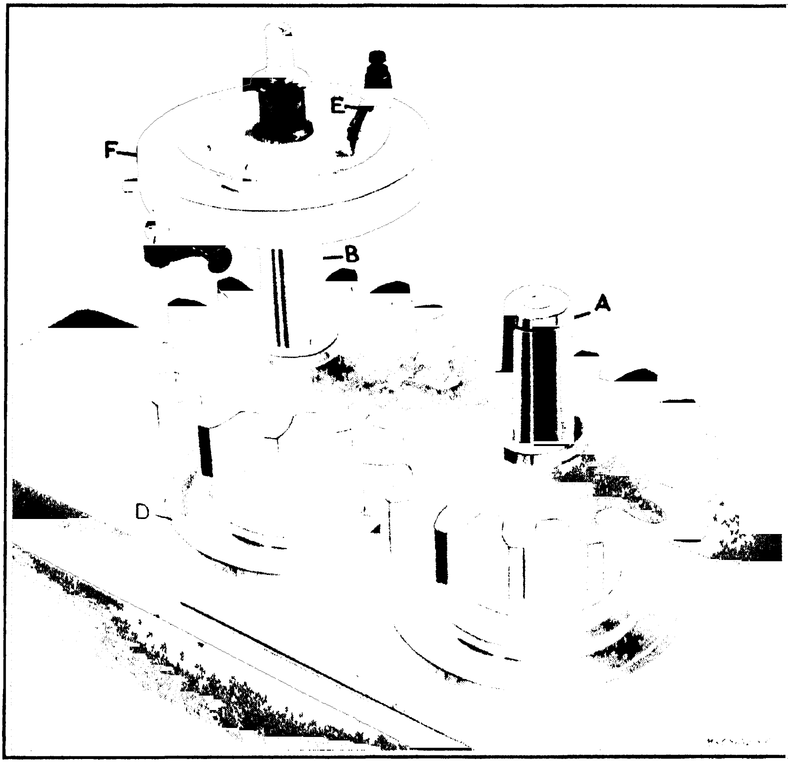


Fig. 31. Machine for testing the Uniformity of Motion between Two Gears

not matter what the exact contour or dimension of any of the operating surfaces may be. On the other hand, if the gears do not accomplish this result, the only good that knowledge of the various discrepancies does, is to indicate the possible causes for the error. This is useful information in the making of the gears, but has little value to the inspector who must decide whether or not the gears are acceptable.

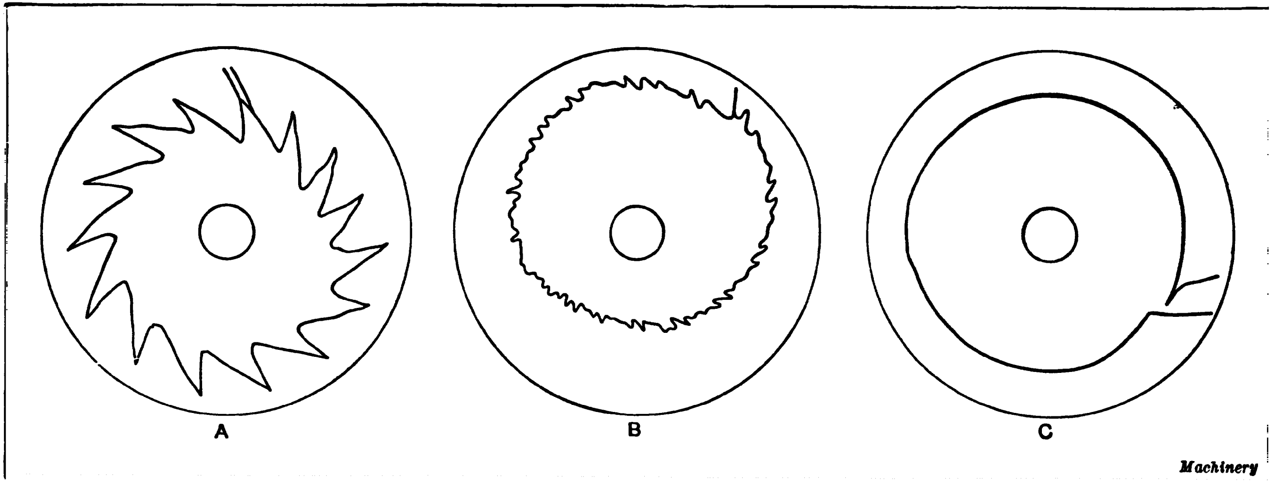


Fig. 32. (A) Chart obtained on Machine illustrated in Fig. 31 from Two Gears cut with Form Milling Cutters. (B) Chart obtained from Two Gears cut on a Gear-generating Machine with a Straight-sided Rack Cutter. (C) Chart secured from Two Gears hardened and then ground in a Grinding Machine of the Molding-generating Type

There are several important factors governing the functioning of the gears: First, the tooth profile; second, the spacing of the teeth; third, the concentricity of the teeth; fourth, the radial position of the tooth profile; and fifth, the relative thickness of the teeth and spaces or the amount of backlash. Errors in any one of the first four factors will cause an error in the uniform transmission of motion. If one of these factors is to be checked to test for this condition, all four should be checked. The simplest

method of testing the backlash is to set the gears in mesh at their proper center distances and actually measure the backlash. Often this can be accurately measured with feeler gages. Another method is to place a piece of soft lead wire between two teeth, run these teeth past the center line, and measure the thickness of the deformed wire.

The principal operating parts of one design of a machine for testing the uniformity of motion between two gears are shown in Fig. 31. This machine or fixture not only indicates the amount of error, but also records it on a chart when desired. Its principle is as follows: The gears are mounted on arbors *A* and *B*, which are spaced to the proper center distance. Under each gear is a plain disk the periphery of which is ground to the pitch diameter of the gear. On arbor *A* both the gear and disk *C* are mounted on the same sleeve; but on arbor *B*, which carries the indicating device, the gear is mounted on one sleeve while disk *D* is mounted on another. Indicator *E* is mounted on the sleeve which carries disk *D*, while an arm which engages with the indicator is attached to the sleeve carrying the gear. Plate *F* which carries the chart is mounted on the fixed arbor *B*.

It will be seen that as the two gears are revolved, the two disks will also revolve, while any differences in the angular position of the gear on arbor *B* and disk *D* will be recorded by the indicator. If the gears are correct, the disks of proper diameter, and there is no slipping between them, a perfect circle will be developed on the chart. An error in the diameters of the disks or slipping between them will develop a spiral on the chart. This makes it easy to detect the errors due to the testing machine. An error of thirty seconds in the angular position of the two gears results in a departure from a smooth line of about 1/16 inch on the chart. The indicator will read errors of ten seconds.

At *A* in Fig. 32 is a chart obtained from two fifteen-tooth gears cut with form-milling cutters. These are the two gears shown in Fig. 31. At *B* is a chart resulting from two fif-

teen-tooth gears cut on a gear generating machine with a straight-sided rack cutter. A chart from two twenty-seven-tooth gears, hardened and then ground in a grinding machine of the molding-generating type, is shown at *C*.

Gear-Measuring Machines. The extensive use of precision gearing in automotive, aircraft, machine tool and other industries has resulted in the development of ingenious special machines for testing the accuracy of different elements. There are a number of different types of these gear-measuring or checking machines. Some of these are designed for checking a given element or dimension, whereas others indicate all errors in combination in such a manner that the individual errors may be analyzed. The characteristic features of some outstanding types of gear-measuring or checking machines will be outlined briefly.

Checking Accuracy of Involute Profiles. One type of machine is designed to check the accuracy of the involute profile. Such machines may be used either for spur or helical gearing. They operate on the well-known principle that all involutes developed from a given base-circle radius are the same. Thus, the shape of the involute changes only when there is a change in the base-circle radius.

One design of involute measuring machine employs a master involute cam. The pointer, which measures the involute, is located automatically at the correct base-circle radius by adjusting the main slide which is located with standard size blocks. The master involute cam is developed from a base-circle radius greater than the maximum capacity of the machine. Gears of smaller base-circle radii may be checked merely by changing the radial distance of the pointer relative to the axis of the gear. If a modified involute is to be measured, a graduated dial is provided, which, in conjunction with a dial indicator, measures the exact amount that the involute is modified and also the angle through which modification extends. One of the latest machines of this general type has an electric gage which

can be used as a limit gage when a number of gears are to be checked and permanent records are not required. This machine can also be equipped with an electrical recording device for charting automatically the involute profiles of the gear teeth.

Another design of machine for checking involute tooth curves checks the gears by using a master rack tooth instead of a pointer. With this arrangement, accurate depth adjustment of a pointer relative to the base diameter of a gear, is unnecessary as the master rack tooth is simply moved into contact with the gear tooth to be checked. This machine has a master base circle integral with the work-holding spindle, and a sine bar which acts as a compensator for the difference between the length of the arc of the master disk and the base circle of the gear, per degree of rotation.

Another type of machine employs a master base circle or disk for each size of gear to be checked. In other words, the diameter of the base circle on the machine equals the base circle diameter of the gear to be checked. The axis of this master base circle coincides with the axis of the gear. The base circle disk bears against a straightedge which is attached to a slide and rolls on the base circle. The contact finger which bears against the side of the tooth being checked is set in the same plane as the straightedge, and, by means of a dial gage, shows any deviations from the true involute as the straightedge is given a traversing movement. In checking helical gears, the contact finger is merely turned to the approximate inclination of the helical teeth.

Measurement of Normal Pitch. The term normal pitch, as applied to helical gears, generally relates either to the normal diametral pitch or to the normal circular pitch. A helical gear, however, also has a *normal pitch* which pertains to the pitch of successive involute tooth curves or profiles. Involute curves developed from equidistant points along a given base circle will be parallel or equidistant at all points if measured in a plane perpendicular to the gear

axis and along any line that is tangential to the base circle. The *normal pitch* of an involute gear is the distance between the corresponding profiles of adjacent teeth, measured as just described.

The normal pitch equals the circumference of the base circle divided by the number of gear teeth. It is often referred to as the *base pitch,* and is an important dimension. Gears may be accurate as to circular pitch or tooth spacing but have errors in the normal pitch. The contact of mating gear teeth is along a line tangent to the base circle or the line of pressure; consequently, when mating gear teeth do not have equal normal pitches, improper contact accompanied by clashing and noisy operation is the result.

A machine has been developed for measuring the normal pitch in the rotational plane. This machine may also be used to check the spacing of various types of gears in planes other than the rotational. This normal pitch and space measuring machine is equipped with contact fingers which are in the rotational or tranverse plane of the gear, and the head of the machine is set to the pressure angle in this rotational plane. A base circle is used to set the contact fingers so that they coincide with the line of pressure. A micrometer may be used for measuring the distance between the contact fingers. After these fingers have been set in position and a dial indicator registers zero, the fingers are backed away from the gear teeth. The overall distance of the two fingers is measured; then the lower finger is measured, and this amount is subtracted from the overall measurement to obtain the normal pitch. These machines may be used for measuring the normal pitch and spacing of spur and helical gears, and the spacing of bevel and worm-gears in the rotational plane. The normal circular pitch of a helical gear may be checked after setting the head to the helix angle of the gear.

Checking Lead of Helical Gears. Another class of gear checking machines is for measuring the accuracy of the lead

of helical gears. With one design of machine, the lead is checked against a master gear or a master disk. The master and the gear to be tested are mounted rigidly so that the axes are in line. A fixed ball point contacts with the master and a similar recording point contacts with the tooth being checked. A traversing movement of the head causes the fixed ball point to rotate the master and gear, as it moves across the master tooth, and the recording point shows any lead errors.

Another design of lead checking machine is equipped with a sine bar which is set to whatever angle represents the correct lead. An indicator is in contact with the gear tooth, and the indicator movement and gear rotation are synchronized so as to show any variation from the proper lead.

Graphic Record of Combined Errors. A type of gear checking machine which has been used extensively produces on a chart a graphic record showing combined errors of such important elements as tooth spacing, tooth profile, interference and eccentricity. The operation of such a machine is based upon the fundamental principle that errors in gear-tooth elements cause either velocity changes or variations in center distance. One design of machine has a master gear that is flexibly mounted so that any errors in the gear being tested affects the center distance between the fixed work-holder and the master gear. Any movements of the flexibly mounted master gear are transmitted through multiplying levers to a pen which traces a line on a constantly moving chart. This chart has parallel ruled lines spaced 0.200 inch apart; and as errors are multiplied 200 times, the distance between the lines represents an error of 0.001 inch. While all errors are recorded in combination by the fluctuating line drawn on the chart, errors such as eccentricity, tooth spacing and tooth shape may be identified readily, and their location and magnitude may be determined. This machine may be used for spur or helical gears, and also for internal gears by means of a fixture.

Tests for Noise. One important object in producing accurate gears is to secure quiet operation, and a machine has been developed for detecting objectionable noise. The gears, while being tested, are operated at high speed inside of an acoustical chamber. This chamber has a horn-shaped projection with an opening to which the operator applies his ear. Objectionable noise is multiplied and detected readily. Each gear is run with its mating gear under load and at the speed, or speeds, at which they will operate when in actual use. Experience is required in order to determine the dividing line between objectionable and unobjectionable noise for a given class of gearing.

Standard Gages. The "American Gage Design Standard" (approved by American Standards Association) is presented as representing the best ideas of industry in general, including gage users and gage makers. Three separate designs have been adopted for plain cylindrical and thread plug gages—namely, the *taper lock* design, the *reversible* design, and the *annular* design.

Taper Lock Design: The term "taper lock" indicates that the gaging member has a taper shank which is forced into a taper hole in the gage handle. This gage possesses the rigidity of a solid gage. The taper lock is used for plain plug gages in diameters ranging from above 0.059 to and including 1.510 inches. The use of this design for diameters above 1.510 to and including 2.510 is optional.

Reversible Design: The reversible type of plug gage is so arranged that the plug can be reversed when one end is worn, thus increasing the life of the gage. This reversible design has three wedge-shaped locking prongs on the handle which engage locking grooves in the gaging member, the two members being held together by a screw thus providing a self-centering support and a positive lock. This design is standard for all plain and thread plug gages in the range of diameters above 1.510 to and including 8.010 inches, with the exception of pipe thread plug gages for which the design

is standard in the range above 2-inch nominal pipe size to and including 6-inch nominal pipe size.

Annular Design: As large plug gages are heavy and difficult to handle, a design was adopted for sizes above 8.010 inches having a minimum of weight consistent with strength and permanence. This annular design has a rim and a web the center of which is bored out to reduce the weight.

Thread Plug Gages: The taper lock, reversible and annular designs have been adopted for thread plug gages, the designs being similar to those used for plain cylindrical plug gages, excepting that the length of the thread gaging members differs in some instances.

Ring Gages: For external size control, the American Gage Design Standard includes plain ring gages above 0.059 to and including 12.260 inches. Ring gages in sizes above 5.510 inches are provided with ball handles. All American Gage Design Standard thread ring gage blanks are equipped with an effective device for adjusting and locking the gage in the manufacturing or resizing processes.

Snap Gages: The American Gage Design Standard includes four designs of adjustable snap gages. In establishing this snap gage standard, the intention was to embody the most desirable features of gages previously manufactured and make it possible to produce snap gages conforming to a common standard.

In the developing of these gages exceptional care was taken to insure embodying all of the best features of snap-gage design including:

1. A design of frame which has proved to be exceptionally rigid under severe tests.

2. Reduction of weight to as low a point as strength of materials permits.

3. Distribution of metal to assure a nice balance and feel.

4. An effective and proved locking device.

5. Suitable construction of gaging pins, buttons, and anvils to give ample rigidity and maintain accuracy.
6. Ease and simplicity of adjustment.
7. Provision for sealing.
8. Careful selection of limits and tolerances to preserve accuracy and permit interchangeability.

Special Gages for Rapid Inspection. Whenever an extremely large quantity of duplicate parts must be continuously inspected, special gaging devices and machines are often designed. Many ingenious indicating devices are used for this purpose. Often a large number of flush pins are operated at one time, and their position is indicated by colored lights, electrical contact being made according to the location of the end of the flush pin. At other times, several gaging devices are built on a surface plate, while the work is moved readily from position to position. Again, in the case of the inspection of cartridges for small arms, special automatic machines are sometimes built for this purpose—machines which require only the services of an operator to feed the work, while the machine automatically gages and sorts the parts. After all, gaging is one of the important operations required in interchangeable manufacturing, and gaging equipment should be designed to meet the particular needs of each component, due attention being paid to the same factors as govern the design of the other manufacturing equipment.

Master Gages and Reference Gages. It is evident that some means of testing gages for their accuracy must be provided. The extent of this testing equipment depends on the ultimate accuracy required. Gages for forgings or other semi-finished parts can be effectively checked with standard measuring instruments, such as micrometers, scales, height gages, protractors, etc. On the other hand, gages for intricate interchangeable parts must be checked with far greater care and require much better measuring facilities. Devices for checking elementary dimensions,



Fig. 33 Size Blocks being used to check the Distance between the Gaging Surfaces of a Snap Gage

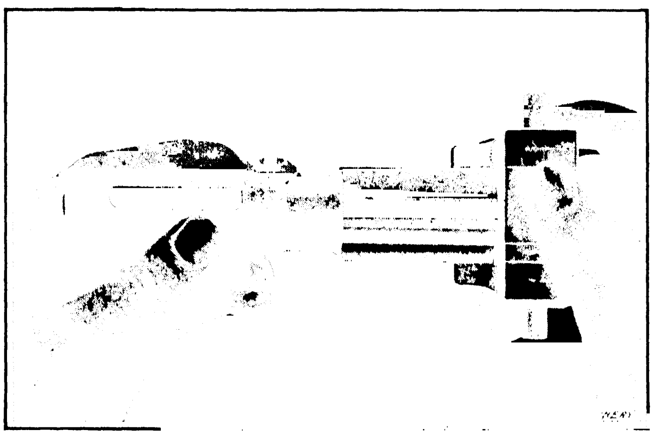


Fig. 34. Application of Size Blocks and End Measuring Attachments for checking the Diameter of a Plug Gage

such as length, diameter, thickness, etc., will be considered first. Measuring machines are on the market for establishing such dimensions within very small limits of error.

Accurate size blocks in sets which can be built up to any desired dimension are also on the market. With such equipment, it is seldom necessary to make special master or

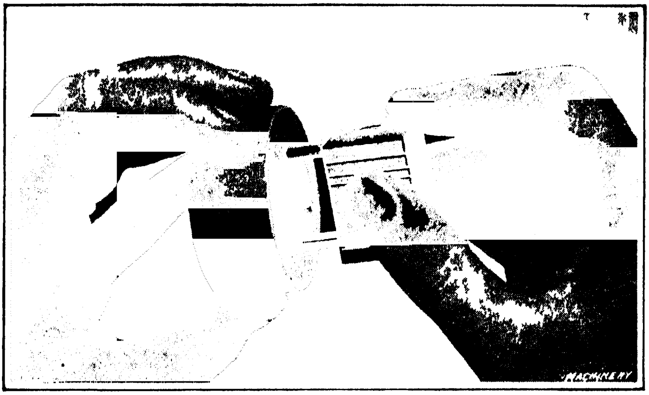


Fig. 35. Checking the Hole of a Ring Gage by Means of Size Blocks and Internal Measuring Ends

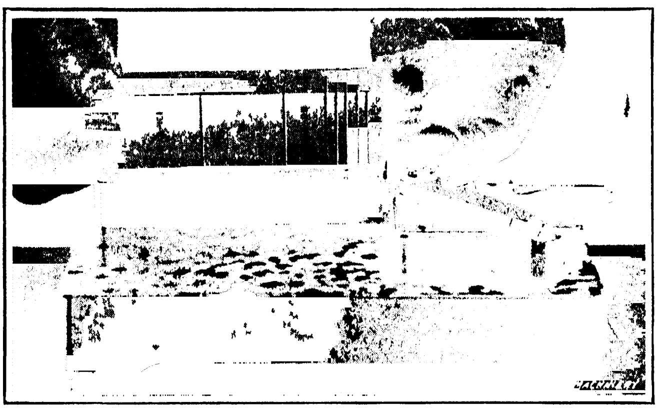


Fig. 36. Employing Size Blocks to test the Distance between Two Pins of a Gage

reference gages for special dimensions. The older practice was to make up special size blocks for every important gage —a practice which was very expensive. A set of size blocks, with a few attachments, will cover a wide field of checking and eliminate the need of the great majority of special reference gages. For example, in Fig. 33, several blocks are being used to check a snap gage. In Fig. 34, with the use of end measuring attachments, several others are used

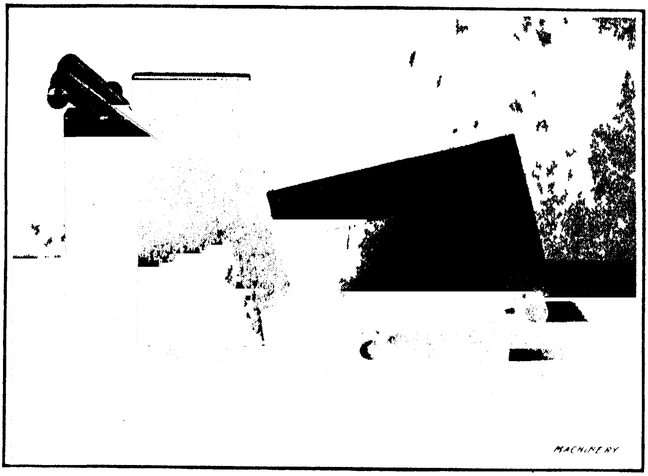


Fig. 37. Use of Size Blocks in Conjunction with a Sine Square for testing the Accuracy of an Angular Surface

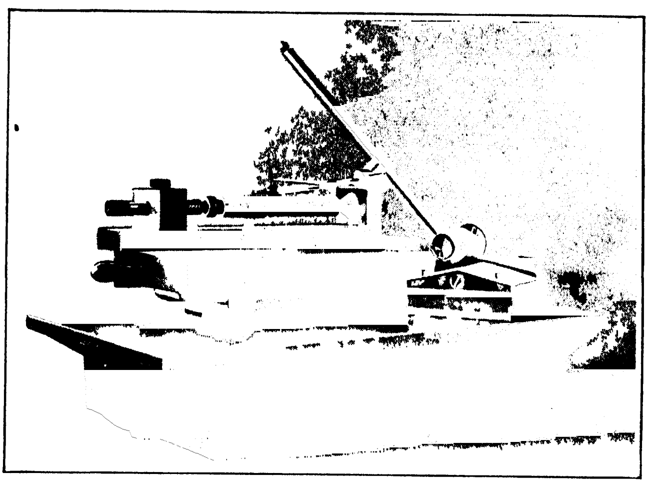


Fig. 38 Illustration showing the Use of a Size Block and Sine Surface Plate in testing a Tapered Part

to check a plug gage. Again, in Fig. 35, size blocks are being used with internal measuring ends to check a ring gage. Fig. 36 illustrates their use in testing the location of two pins in a gage. A more elaborate set-up is shown in

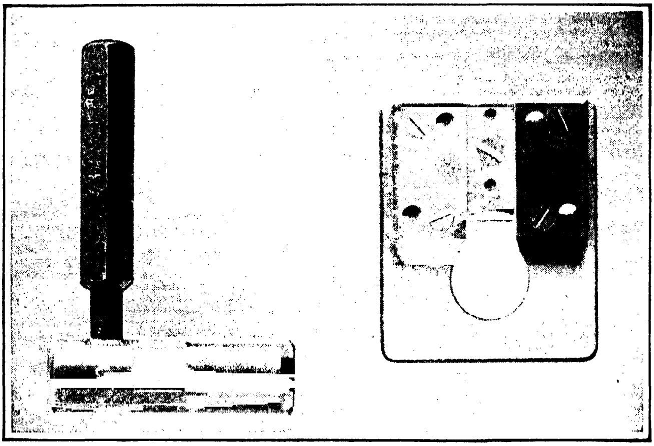


Fig. 39. Gage for testing a Composite Surface, and Reference Gage employed in its Checking

Fig. 37. Here a sine square and size blocks are employed for testing the accuracy of an angular surface. Fig. 38 shows their use with a sine surface plate to test a taper.

In each of the above cases, every surface has been treated as an elementary surface for the purpose of testing. For the rapid testing of composite surfaces, however, special master or reference gages are required. Sometimes these masters are tried directly on the gage. Such is the case with the master shown to the right in Fig. 39. In other cases, the master is a duplicate of the gage itself, and the gage is tested by comparative measurements from the master. This is common practice with plug thread gages. A measurement is taken with thread micrometers or over wires on the master gage, and a similar measurement is taken on the gage itself. The comparison between the two measurements determines the conditions of the gage.

CHAPTER X

INSPECTION AND TESTING

THE proper inspection of the many parts of an interchangeable product is one of the most important as well as most difficult tasks in manufacturing. On the one hand, if inspection is carried on in an arbitrary and exacting manner, it will retard production and increase the cost of manufacture. On the other hand, if it is done in a perfunctory and lenient manner, it is worse than useless, as it will not prevent the sending out of an unsatisfactory product. The principles of inspection formulated in this chapter, if correctly applied, will promote the economical production of parts on an interchangeable manufacturing basis and will insure that all requirements are met.

With any system of inspection, the tendency of the productive departments is to neglect all thoughts of the ultimate use of the parts in process and to concentrate on efforts to increase production, the standard of quality apparently being anything that the inspector will not reject. Thus, an unfortunate situation almost inevitably arises, the production departments considering only the detailed manufacturing problems and constantly seeking the line of least resistance as regards the machining; while the inspectors either connive at this or arbitrarily insist on the exact letter of the drawings and specifications without regard to the ultimate use of the part in question.

Neither of the above forms of inspection is satisfactory. In previous chapters, it has been pointed out that seldom, if ever, are the drawings and specifications complete or correct enough to be followed blindly. The mere meeting of the drawing requirements is not in itself the prime object of manufacturing. The main purpose in all branches of interchangeable manufacturing is to promote the economical production of satisfactory mechanisms. If the inspection is to accomplish its part in this

work discretion should be used, and due consideration should be given to many factors.

Discrepancy between Part and Drawing. When a piece of work is not in accordance with the component drawing, any one of several conditions may be present: First, the part may be wrong and the drawing correct. Second, the part may be correct and the drawing in error. Third, both the part and the drawing may be correct. And fourth, both the part and the drawing may be wrong. In the first case, if the part cannot be salvaged, it must be scrapped. In the second case, the part should be accepted and steps taken immediately to have the drawing corrected. The third case requires more consideration. For almost every problem there is more than one satisfactory solution. If the part as made can be reproduced at a lower cost than one in accordance with the drawing, the part should be accepted and the drawing corrected accordingly. But if the part as made is more difficult to reproduce, the drawing should remain unchanged, although the part need not be rejected. In the fourth case, if the part cannot be salvaged, it is, of course, scrapped; but the necessary corrections should be made on the drawing as soon as possible.

In all of this work, due consideration must be given to the succeeding manufacturing operations and the equipment provided for performing them. When elaborate manufacturing equipment is provided, it is often cheaper to scrap parts that might otherwise be salvaged, because of the difficulty of completing them with the existing equipment. It is obvious that when a great volume of production is involved, discretion can be exercised by but few of the inspection personnel. Hence any abnormal volume of rejections by the inspectors should be the occasion for a reinspection of the rejected parts by suitable persons competent to locate the error, whether in parts or drawings.

Incomplete Drawings and Specifications. The original drawings seldom give information complete in every detail which is necessary to produce every part. The production departments, however, must complete the parts with or without the assistance

of the drawings and specifications, while the inspection department must decide whether or not the parts thus produced are satisfactory. The first solution of some of these indefinite points may not be the best one, and several different methods may be tried out before one that is entirely satisfactory is reached. During all this development, the inspector must give a great deal of consideration to the problem so as not to delay production unnecessarily and still insure a satisfactory product. As soon as any problem is solved, the inspection department should be responsible for passing the information along to the proper persons so that it may be recorded.

Position of Inspection Department. This makes it clear that the inspection department, among its other duties, must act as eyes for the engineering department. For this reason, in some plants the inspection department reports to, and is virtually a part of, the engineering department. In other plants, it is a distinct department and is responsible to the management. Either plan usually works out well. In no event should it be a part of, or subordinate to, any production department. The duties of the production and inspection departments are so incompatible that they should never be combined, and if they are, one or the other is bound to suffer. Nevertheless, the inspection should be carried on in close cooperation with the production departments, and all other departments of the organization.

The mechanical inspection of component parts falls logically into two main divisions: The first is the shop inspection which is performed while the parts are in the process of manufacture. The object of this inspection is to cull out defective work as early as possible and to discover any defects in the manufacturing equipment which result in faulty work. The second division is the final examination of the completed parts. The object of this is to see that all components that will function properly are accepted, and all unserviceable parts rejected. There is also the inspection, or testing, of the assembled mechanism to detect faults that have not been detected prior to assembling the parts.

Shop Inspection Methods. When the production is continuous, the shop inspection should be so established that the

parts are rigidly inspected after each machining operation on every important functional surface. The requirements of these surfaces should be definitely determined and recorded as early as possible, and these requirements should be rigidly maintained. These inspections are as important as any of the productive operations, and should be maintained accordingly. The inspection of non-functional and other unimportant surfaces can usually be handled by an inspector who passes from department to department and periodically checks a small percentage of the product at each machine. If errors are discovered, the machine should be stopped and the set-up corrected, but the parts at fault should not necessarily be rejected.

The inspectors are, of course, supplied with the necessary gages, limit gages being essential for most of the important functional surfaces, while "go" gages alone are usually sufficient for surfaces of lesser importance. Definite lists of the essential inspections or important functional surfaces should form a part of the specifications. These may be combined with the operation lists or may be made up as separate schedules. Whether or not each individual piece of work should be inspected depends largely on the character of the operation. On many automatic operations, a percentage inspection is sufficient; while on most hand operations, where each piece is handled individually and the personal skill of the operator is a factor, a one hundred per cent inspection is usually required.

The inspection of screw machine parts made from bar stock is a case where the inspection of a minor percentage is sufficient. The practice in one plant is as follows: Each automatic screw machine has, as part of its equipment, several small metal work boxes or baskets which are numbered consecutively. These are used in order, and about every fifteen minutes the one on the machine is removed and placed on a bench, while the one with the next number is placed on the machine. An inspector makes periodical visits and inspects a few parts from each basket. If these are satisfactory, all the parts are removed and the empty basket is returned to the machine operator. If a faulty piece is found in any basket, the entire contents of that basket, all suc-

ceeding ones, and also the one preceding it, are set aside for a one hundred per cent inspection while the machine is stopped immediately and its set-up corrected.

This general plan is adaptable to many other operations, such as sub-press die work and other punch press operations, for example, where the set-up and condition of the tools alone practically control the uniformity of the product. The shop inspection should be carried on as soon after the machining operations as possible. In the case of very large parts, the piece is often inspected before it is taken from the machine, which saves a new set-up if corrections are necessary.

Personnel of Shop Inspection. Much of the detail work of testing the parts with gages, particularly on small work, requires little mechanical knowledge or skill, and is often satisfactorily performed by girls. When the quantity of production is large, and the inspections are subdivided into elementary tasks, a relatively small amount of training will develop efficient detail inspectors. The supervisor of such work, however, should be not only a good mechanic, but also a person well acquainted with the requirements of the product. The successful chief inspector must be firm but diplomatic; his duties must never degenerate into faultfinding.

The person in charge of the shop inspection has one of the most difficult positions to fill. A great part of his work in promoting economical production is to prevent faulty parts from being made. When an operation is first set up, the product should be checked. If it is satisfactory, the succeeding parts must be watched so that the set-up may be corrected before any work is spoiled. If the first parts do not meet the requirements, the set-up must be corrected before production in quantity is started. To fulfill these duties properly, without antagonizing those engaged in production, is a delicate task and the closest cooperation is necessary. An arbitrary inspector will soon stop production entirely. On the other hand, an inefficient inspector can soon ruin the reputation of the firm. A grave mistake on the inspector's part in either direction will inevitably cause much needless expense.

Final Inspection of Work. In many ways the function of the final inspection is quite different from that of the shop inspection. The latter deals with the parts as they are being shaped from the raw material. Nothing should be left undone to promote their completion in accordance with the drawings and specifications. The final inspection, on the other hand, deals with the parts after all the machining operations have been completed. Its main function is to see that all parts which will give satisfactory service are accepted, and that those which will not are scrapped. This result alone should be striven for, regardless of technical violations of the drawings and specifications. Under normal conditions, such violations should be rare. If conditions are abnormal, steps should be taken to correct them, but such steps should not involve rejection of serviceable parts.

In general, gages used in the final inspection should be functional gages only. If the detailed shop inspection is properly organized, there is no need to duplicate it here. If it is not functioning properly, the trouble should be corrected at its source. Both the shop inspection and the final inspection should be under the general direction of the same person. All final decisions as to the acceptance of questionable material, whether questioned by the shop inspection or the final inspection, should also be made by the same person.

One of the duties of the inspectors who perform the final inspection should be to watch the work of assembly, in addition to testing the assembled product. If the component parts assemble properly, and the completed mechanisms function as they should, no further evidence is needed that the productive work has been properly done. If the parts give trouble in assembling, or the mechanism fails to function, immediate steps should be taken to locate the trouble and correct it at its source. Thus the assembling departments form the best points of vantage to watch and judge the results that are being obtained.

Inspection of Gages and Material. The inspection of the gages used in the course of manufacture is one of the vital functions of the inspection department. As gages become worn, they permit parts larger or smaller, as the case may be, to pass

inspection. The adjustment of a machine or tool is not changed as long as the parts produced satisfy the gages used in their inspection, and so all gages should be checked periodically and corrected or replaced as found necessary. Too often this is not done until trouble has developed. One of the principal objects of inspection is not to locate the cause of trouble after it has happened, but to forestall and prevent it. A systematic inspection of gages is a sure means of accomplishing this end.

Most of the inspection of the composition and physical strength of materials belongs in the chemical and metallurgical laboratories. When a part is subjected to unusual stress, it is customary to make a chemical analysis of each bar of stock as it is received. This, and other specified physical tests, are seldom considered in connection with the mechanical inspection of the product. Often, however, after such operations as forging, hardness tests are made in conjunction with the other inspections to insure that the metal is in proper condition to be readily machined. Such tests are usually made with simple testing instruments, such as a Brinell testing machine or a scleroscope, the mechanical operation of which requires no more skill than the proper handling of gages, and are, therefore, usually conducted by the regular mechanical inspection personnel.

Testing of Assembled Mechanisms. Whenever possible, the assembled mechanism is tested by actually having it perform the work it is intended for. Thus, a newly completed automobile is usually sent out for a road test before being shipped; a typewriter is manipulated by an operator; a rifle is tried out by a marksman, etc. These tests, of course, only prove the condition of the mechanism while new. The test of service depends upon the materials used in its construction and the honest workmanship which has been built into it at every stage beginning with the designing and followed by the careful and watchful work of the productive operators, the vigilance and good judgment of the inspectors, and the care and attention of the assemblers. No one factor is predominant. All are essential and each one must be carefully studied in order to develop and maintain a smooth flow of production.

CHAPTER XI

MANUFACTURING FOR SELECTIVE ASSEMBLY

Selective assembly manufacturing is a method of manufacturing which is similar in many of its details to interchangeable manufacturing. In the selective assembly, the component parts are sorted and mated according to size, and assembled or interchanged with little or no machining. Because of their similarity, the two methods are often confused, and this has led to misapprehensions in regard to the principles of interchangeable manufacturing. The production of many commodities involves both methods of manufacture and this has led to even greater confusion. The general principles of both of these methods are compared in this chapter for the purpose of explaining the principles involved.

The chief purpose of manufacturing, by selective assembly or interchangeable methods, is the production of large quantities of duplicate parts as economically as possible, within such limits that they may be assembled without further machining. In order to achieve this, close attention must be paid to the basic principles governing production, including the design of the mechanism and the process of manufacture.

The general principles of design are identical for manufacturing on an interchangeable basis and on a selective assembly basis. The functional design must first be made and tested, then the manufacturing design developed. This modifies the inventive design so that the product may be manufactured on a large scale in an economical manner. This subject of design was discussed in a previous chapter. One point, however, should be kept constantly in mind. It is seldom that every part of a mechanism is to be made for selective assembly. Usually a very small percentage of the parts are so made.

A model mechanism is the representation of the design in metal. Thus, as with the design, the general principles and purposes of

the model are identical for both interchangeable and selective assembly manufacturing.

Clearances and Tolerances in Selective Assembly Manufacturing. The matter of clearances and tolerances is quite different when manufacturing on an interchangeable basis from when manufacturing on the basis of selective assembly. In interchangeable manufacturing, the minimum clearances should be as small as the assembling of the parts and their proper operation under service conditions will allow. The maximum clearances should be as great as the functioning of the mechanism permits. The difference between the maximum and minimum clearances establishes the sum of the tolerances on the companion surfaces.

When this allowable difference is smaller than normal manufacturing conditions will permit, however, parts cannot be economically manufactured on an interchangeable basis. In such cases one of two courses is open. First, excess metal may be left on one part which is fitted at assembly — this usually proves an expensive process; or second, tolerances can be established which enable the parts to be manufactured economically and then sorted and assembled according to their size. This second method is known as selective assembly manufacturing. There are several methods of attaining this end. In general, the usual method consists of treating the more intricate companion parts like interchangeable parts; that is, making the basic dimensions on one part represent the maximum metal conditions, and having the tolerances define the minimum metal conditions. The extent of the tolerances, however, will be determined by the extent of the normal manufacturing variations. The basic dimensions of the companion part would represent the minimum metal condition — not the maximum metal sizes as in interchangeable manufacturing — and the direction and extent of the tolerance would be identical with the first piece.

The practice, which is correct for selective assembly, of making the tolerances represent the normal variation of the manufacturing process employed, is often mistakenly used when manufacturing on an interchangeable basis. If such a practice adds

nothing to the expense of production, there is no harm in employing it; but too often it imposes unnecessary refinement in manufacture, as in almost every case, the closer the tolerances, the more exacting and expensive will be the manufacturing processes. With selective assembly manufacturing, on the other hand, the closer the tolerances, the fewer the subdivisions in size that will be required, and the smaller the stock of parts it is necessary to carry. This introduces a factor in selective assembly manufacturing which is not present in interchangeable manufacturing. The economical balance between the increased cost of manufacturing to closer tolerances and the decreased cost of investment represented by a smaller stock of different sized parts establishes the proper course to follow when manufacturing on the basis of selective assembly. Ultimate economy here, as elsewhere, is the main end sought.

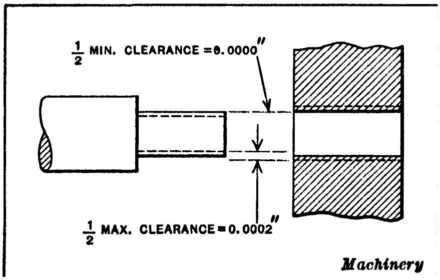


Fig. 1. Proper Assembling Conditions in Selective Assembly

Dimensions and Tolerances on Component Drawings. Many of the general principles in regard to component drawings for parts made for selective assembly are the same as for interchangeable parts. Several details vary, however, due to the differences in treating the clearances and tolerances. In both cases the effort should be made to so give the dimensions and necessary tolerances on the drawings that it will be possible to lay out one, and only one, representation of the maximum metal condition and one, and only one, minimum metal condition. In addition to this, for selective assembly, some notation must be made to indicate the proper grading and classification according to size. Thus, in selective assembly manufacturing, there will be a double set of limits, the first being the manufacturing limits, and the second the assembling limits.

Take, for example, the stud and hole shown in Fig. 1, which

give the proper assembling conditions. The minimum clearance is 0.0000 inch while the maximum clearance is 0.0004 inch. Assume that the normal manufacturing variation on each part will be 0.0010 inch. Fig. 2 gives one method of notating both sets of limits. Any studs in Group A, for example, will assemble in any hole in Group A, but the studs in one group will not assemble properly in the holes in another group. The example stated shows one method of grading parts when both of the companion parts are to be sorted before assembly. Many times in actual practice, when one of the parts is complicated, and the majority of its surfaces are interchangeable ones, the minor

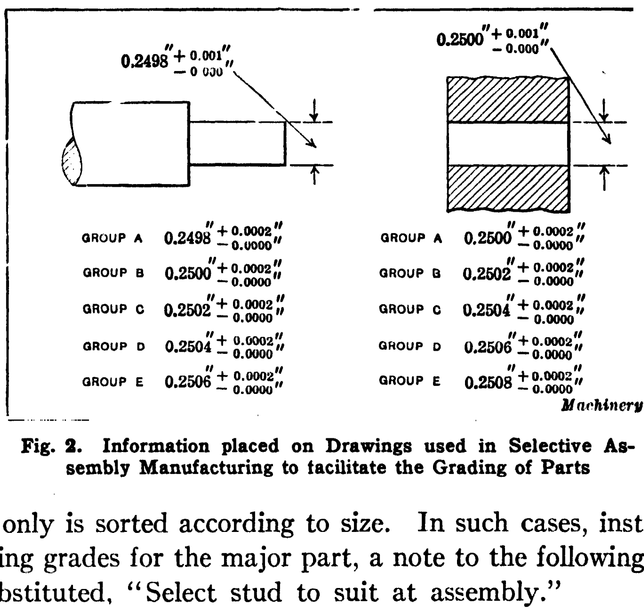


Fig. 2. Information placed on Drawings used in Selective Assembly Manufacturing to facilitate the Grading of Parts

part only is sorted according to size. In such cases, instead of defining grades for the major part, a note to the following effect is substituted, "Select stud to suit at assembly."

In many cases, two separate drawings are made of a part which is to be graded before assembly. One shows the manufacturing tolerances only, so as not to confuse the machine operator, while the other gives the proper grading information. In Chapter V, five laws of dimensioning were given for interchangeable parts. All of them, except the third, apply equally to parts which are selectively assembled. The laws which apply to this method of manufacture will be given again.

Laws of Dimensioning for Selective Assembly. 1. In manufacturing, there is only one dimension (or group of dimensions) in the same straight line which can be controlled within fixed tolerances. This is the distance between the cutting surface of the tool and the locating or registering surface of the part being machined. Therefore, it is incorrect to locate any point or surface with tolerances from more than one point in the same straight line.

2. Dimensions should be given between those points which it is essential to hold in a specific relation to each other. The majority of dimensions, however, are relatively unimportant in this respect. It is good practice to establish common location points in each plane, and to give, as far as possible, all such dimensions from these common location points.

3. This law relates to the proper basic dimension to be given on the component drawing. In selective assembly the conditions which must be met are so different, that no general rule in this respect can safely be given. Each case requires special consideration.

4. Dimensions must not be duplicated between the same points. The duplication of dimensions causes much needless trouble, due to changes being made in one place and not in the others. It causes less trouble to search a drawing to find a dimension than it does to have them duplicated and more readily found but inconsistent.

5. As far as possible, the dimensions on companion parts should be given from the same relative locations. Such a procedure assists in detecting interferences and other improper conditions.

Similarity of Specifications, Equipment, Gages, and Inspection Methods. The general principles of specifications for interchangeable manufacture, which were given in Chapter VII, hold true for manufacturing on a selective assembly basis. Particular care should be taken to specify clearly the parts to be so manufactured and the method of grading to be followed. If the component drawings are properly made, there is no difference in the actual productive operations between manufacturing on

an interchangeable and on a selective assembly basis. In both cases, the task is to produce parts within specified tolerances. Therefore, the conditions governing the design of the manufacturing equipment are constant.

The working and shop inspection gages for either interchangeable parts or those made for selective assembly are similar. Additional gages for the purpose of grading, however, are required for the final inspection. Often these are indicator gages, which promote the rapid sorting of the product. In other cases, gages with successive steps or with slightly tapered measuring surfaces are used.

The detailed shop inspection differs in no particular from that employed in interchangeable manufacturing. The only difference is the addition of the selection and grading of the parts after completion. Sometimes the actual selection takes place at the assembly itself. If the first part tried is too large or too small, another is chosen which assembles properly. If the rate of production is relatively low, this procedure is often satisfactory. In fact, it is often observed in the assembly of parts which are supposed to be interchangeable. But if the production is high, too much time will be lost by the assembler to make the practice economical.

In general, manufacturing on an interchangeable basis will be found more economical than manufacturing on a selective assembly basis, provided the design permits sufficient clearances to allow reasonable manufacturing tolerances. In the first place, a larger stock of parts is required for selective assembly to insure that companion parts of suitable sizes will always be available. In the second place, the additional expense of sorting, whether done by an inspector or by the assembler, is involved in this method of manufacture. In its actual operation, the main difference between selective assembly and interchangeable manufacturing is that overlapping tolerances are required in selective assembly while such tolerances are absolutely wrong in interchangeable manufacturing.

CHAPTER XII

SMALL-QUANTITY PRODUCTION METHODS

INTERCHANGEABLE manufacturing methods, as considered in previous chapters, relate to a comparatively high rate of continuous production for which the expense of a complete equipment of special tools, fixtures, and gages is justified, and for which the time and constant study required to keep the component drawings in proper shape is essential to prevent any break in the continuous flow of production. But, when any commodity is manufactured intermittently in small lots, the cost of such procedure is often greater than the results justify. Nevertheless, many of the principles involved in interchangeable manufacturing can be applied with economical results to the production of small quantities.

When comparatively few machines of one type are manufactured, few parts are duplicated in great numbers, and so, similar surfaces, rather than similar parts, should receive attention. This requires a thorough analysis of the four following factors: (1) The possibilities of standardizing the nominal sizes so as to have the smallest possible number; (2) the possibilities of standardizing the minimum clearances between companion parts for each standard size to meet the various functional conditions; (3) the possibilities of standardizing the tolerances for the various standard sizes and conditions; and (4) the determination of the best surface to be maintained as a standard size; that is, whether it should be the maximum male surface or the minimum female surface. Until these factors are determined, it will be difficult to lay out a simple and consistent procedure that will result in economical production.

One caution must be given before further discussion is made of the subject of standardization. In order to obtain the best results, all known conditions involved must be given due weight; but the consideration given to any factor should depend on the

frequency of its occurrence. One usual condition will far outweigh several exceptional conditions. An unusual condition, will always require special consideration regardless of attempts at standardization. If an established standard will not meet the required condition, it should not be used. Regardless of the extent of standardization, exceptions will always occur and must be dealt with. Thus, a standard is theoretically the best construction that will satisfy the majority of the known conditions. In practice, however, all existing conditions must be met. Therefore, if an established standard is unsatisfactory for any particular service, unusual conditions are present and must be met.

Standardization of Nominal Sizes. In machinery manufacture, it is evident that if the number of nominal sizes of commonly used parts is reduced, the number of standard tools and gages required in the production department will be reduced correspondingly. As an example, the matter of reducing the number of nominal sizes of shafting may be cited. Prior to the adoption of the American Standard, two distinct but closely related problems were considered. First, the standardization of the diameters of shafting used for the transmission of power, such as lineshafts and countershafts, etc. This usually consists of cold-drawn shafting which is used without machining. The following eighteen sizes have been adopted as standard for this type of shafting: 15/16, 1 3/16, 1 7/16, 1 11/16, 1 15/16, 2 3/16, 2 7/16, 2 15/16, 3 7/16, 3 15/16, 4 7/16, 4 15/16, 5 7/16, 5 15/16, 6 1/2, 7, 7 1/2 and 8 inches.

The second problem related to the standardization of the diameters of machinery shafting such as is used by manufacturers of machinery of various types. For this purpose, the following sizes have been adopted as standard: Sizes from 1/2 inch up to 2 1/2 inches, increasing by intervals of sixteenth inches; from 2 1/2 inches to 4 inches, inclusive, by eighth inches; and from 4 to 8 inches by quarter inches. The foregoing sizes are sufficient to meet the majority of conditions. If proper attention is given to this point in the design of a mechanism, the use of unnecessary intermediate sizes will be eliminated.

Standardization of Minimum Clearances. The amount of the minimum clearance between companion parts depends on many

factors. Among them are the size of parts, the length of the bearing, the class of fit required, and the conditions, such as temperature, etc., under which they must operate. The classes of fits which apply to cylindrical parts, for example, may be approximately summarized as follows: (1) Running fits, where one part must revolve freely; (2) sliding fits, where one part must slide freely; (3) push, or dowel fits, where neither part is required to revolve but where both parts must assemble readily, and be held in alignment; (4) force, driving, or shrinkage fits, which are made with pressure or by shrinkage, and used in assembling parts which must be held in fixed positions.

The amount of the minimum clearance for a running fit is dependent, to some degree, on the length of the bearing. A long bearing, for example, may have a somewhat greater clearance than a short one. The proper length of the bearing depends on the load and the material used in the bearing. The load controls, to a large extent, the diameter of the bearing. Thus, the first step toward standardizing the minimum clearances is to determine the most common material employed in making the bearings, and to establish standard lengths of bearings for the various diameters of shafts. The exceptions which will inevitably develop must, of course, be treated on their own merits. Take, for example, a long feed-screw or a long bending roll which is supported on the ends. Regardless of the diameter or length of the bearing, greater minimum clearances than the established standard would be required. If the number of similar exceptions is appreciable, supplementary standards can be developed to meet them.

Another factor which must be considered before the standards can be safely established, relates to the conditions under which the parts must operate. Thus, if the parts must operate when subjected to higher or lower temperatures than normal shop temperatures, due allowance must be made. On the other hand, if such temperatures are the exceptions, the corresponding clearances must be exceptions. A good example of this occurred with a concern that manufactures power presses, several of which were ordered by a plant in Alaska. The shed in which the presses

were set up was unheated; for this reason the lubricating oil became very heavy, and the presses would not work properly until the clearances in the bearings had been increased sufficiently to permit the heavier oil film.

In a similar manner, standards for all other classes of fits desired should be developed, not only for cylindrical but also for all other common surfaces. Every attempt should be made to standardize the more common surfaces and conditions first, and the others as it proves advisable.

Standardization of Tolerances. When manufacturing interchangeable parts in large quantities, the tolerances should be as great as the functioning of the mechanism permits, in order to secure the greatest economy of manufacture. As the functional conditions will vary so much, this practice seldom permits any great standardization of tolerances. On the other hand, when manufacturing in small quantities, using standard tools and equipment wherever possible, the tolerances should represent, as far as possible, results which may be consistently obtained with the use of standard tools and which will insure that the parts will function properly. The first step, therefore, toward standardizing the tolerances is to determine the accuracy of parts produced by the various manufacturing methods. In this way, standard tolerances for each method will be developed, such as tolerances for grinding, reaming, drilling, boring, finish-turning, rough-turning, milling, planing, etc. The next step is to establish a practice for machining the various functional surfaces according to the requirements which they must meet. For example, on shafts, all running fits should be ground, all bearings should be reamed, etc. In general, the extent of the tolerances will increase as the sizes of the parts increase. Thus, for each method of manufacturing, a standard tolerance should be determined for each standard size.

Maximum Male or Minimum Female Size as Standard. In considering whether the maximum male or minimum female basic size should be the standard, shafts and their corresponding holes will be dealt with. In general, the tools for making the holes, such as drills, reamers, etc., are nonadjustable, while the

tools for machining the shafts are either adjustable in themselves or are carried on adjustable members of the manufacturing machines. This makes a strong argument in favor of maintaining the basic size of the holes as standard. This practice is now becoming quite universal. Of course, an exception to this will always occur when cold-rolled shafting is to be used without machining.

A little study will show that this practice can be applied to advantage on other surfaces. The basic dimension of the width of a slot or groove can be kept standard, and the necessary clearance can be provided by reducing the size of the mating member.

Effecting Economy by Using Standard Parts. The development and use of standard parts offers one of the greatest opportunities for economy in the manufacture of small lots of commodities. The greatest difficulty in the way of accomplishing this is the necessity of training the designers to use them. There seems to be a fear among these men that the extensive use of such standard parts will limit their initiative and curtail their originality. The fact is the extensive use of standard parts will eliminate a large amount of the designer's drudgery, thus freeing much of his time and thought for creative work.

In order to promote the use of standard parts, records relating to them should be made in a simple and convenient manner. Certain types of parts, such as levers, gears, bushings, studs, pulleys, etc., should always be considered as potential standard parts, even if certain of them are used merely in a single place, and should be tabulated or indexed for ready reference. In this way a series of standard parts is readily begun. After the start, a study should be made and a balanced series laid out to cover possible future needs. Otherwise the series will be unbalanced, that is, the differences between some of them will be very small, while between others they will be very great. Such a series would eventually contain an excessive number in order to cover a

given range. The essence of standardization is to reduce the number of standards to a minimum.

Standardizing Unit Assemblies to Suit Several Machines. The design of the commodity which is to be manufactured in small lots should be carefully studied and every opportunity taken to incorporate smaller unit assemblies. As with many of the component parts, each unit assembly should be considered as a potential standard. If this is done, many of them, such as oil-pumps, speed- and feed-boxes, reversing mechanisms, etc., will be found applicable to several machines.

An interesting example of what is possible along these lines is illustrated by the application of a speed-changing mechanism to various types of machine tools. This speed-changing mechanism (of 10 horsepower capacity) was designed as an independent unit to permit using it on several different types of machine tools. One application was to a radial drilling machine, the mechanism being attached to the rear. Another application was to a large slotter. This same design of speed-box was also applied to different types of horizontal boring machines. The various types of machine tools referred to are made in small lots as required, but these speed-boxes, and other common standard parts, are made in relatively large lots and carried in stock. This example indicates to a small degree the many possibilities along these lines.

It is of interest to note in this connection that one large corporation which controls several plants building many different kinds of machine tools, has adopted a standardization program to simplify manufacturing practice. Certain types of parts and some unit assemblies which have been developed at the different plants have been compared and discussed.

In most cases, this discussion has led to the adoption of a certain series of them as standards for all plants. In addition, the plant best fitted for that particular work has been

selected to manufacture all of such parts or unit assemblies for all the plants. In this way, the economies resulting from producing in large quantities are secured, where no one of the plants involved has a very large production of any one size and type of machine tool. As with standard parts, if any extensive use is to be made of standard unit assemblies, they must be recorded and tabulated in a simple and convenient form for ready reference.

Component Drawings for Small-quantity Production. The component drawings of a mechanism which is to be manufactured in small lots will vary considerably from those used when the production is large. As a rule relatively few of the operating clearances and also few of the manufacturing tolerances will be specified. Notes, such as "force fit," "running fit," etc., will be the usual method of noting this information.

To determine properly the correct clearances and tolerances for any surface, much time is required for studying the design, checking results obtained on the various surfaces in production, etc. When parts are made in small quantities, there is little or no opportunity to do this work, although to specify these requirements without such study is generally useless. At best they are only a guess, and are often established by some one who knows little of the actual working conditions.

When a part becomes standard, or when elementary surfaces as in holes and on shafts are standardized, the production of these parts and surfaces is large enough to permit the necessary study and tests to be made. Here the component drawings should specify the maximum and minimum sizes exactly as in the case of component drawings for large-quantity production. A full discussion of the requirements of such drawings is given in Chapters V and VI.

Manufacturing Equipment. Relatively little special manufacturing equipment is provided for manufacturing in small lots. Generally nothing more than boring jigs and

planer templets is necessary. The machine operators are usually skilled machinists and perform most of the machining cuts on standard machine tools with the use of standard cutting tools. Each piece of work is set up and clamped to the bed of the machine with only the aid of standard measuring tools to test its position. With such a type of operator, the component drawings do not actually require the same amount of detailed information as is necessary when the work is performed by less highly skilled labor.

In many cases, not even boring jigs or planer templets are provided; the work is first laid out, and then the machining cuts are taken to match the lines drawn. As the production increases, however, more and more special manufacturing equipment can be used to advantage. As the quantities become large enough to pay for the cost of this equipment, its provision and use will greatly promote economical production. The essential requirements of this equipment, whether much or little is provided, are identical with the requirements of equipment for manufacturing large quantities.

Gages and Methods of Inspection. The gages used in this type of manufacturing consist principally of standard measuring instruments and plug, ring, and snap gages of standard sizes. Thread gages for standard threads are also used to an appreciable extent, as well as adjustable snap and plug gages which may be set with the aid of standard measuring instruments or standard size blocks. Where adjustable gages are used, it is very desirable to have means for sealing them so that they may be adjusted in the tool-room but not promiscuously in the shop.

When boring jigs are provided, these form in themselves effective gages for testing the location of holes by using suitable plug gages and bushings in place of the boring tools. When planer templets are employed, these also make effective gages, an indicator being substituted for the planer tool. As with other manufacturing equipment, gages should

not be provided until the volume of production is great enough to make their use economical.

The inspection of parts made in small quantities, where stock is left on many pieces for fitting at assembly, and where the component drawings give incomplete information, is quite different from the inspection of parts made in large quantities. The extent of the inspection required depends to a large extent on the methods of paying the workmen. For example, when the wage is paid on a time basis alone, this inspection is relatively slight. On the other hand, if piecework prices or bonuses are paid, a more complete inspection is required, as a bonus should not be given for spoiled work.

Most of this inspection requires a skilled workman, as little special gaging equipment is available, and this necessitates the use of standard measuring instruments in many cases and also many special set-ups. In addition, with the incomplete component drawings, the inspector must be sufficiently experienced to tell whether or not the parts as completed will function properly when no fitting is to be done at assembly. When fitting is required, he must also be able to determine whether or not the amount of stock left for this purpose is suitable.

On large pieces, the inspection should be made while the part is set up on the machine used in finishing it, so that if corrections are necessary, they can be made without an additional set-up. When no special locating fixtures are employed and a part is removed from the machine, it is almost impossible to relocate it in order to correct one surface and yet keep the proper alignment with the other finished surfaces. The inspector should be capable not only of detecting errors, but also of convincing the workman of them without antagonizing him. The inspection of standard parts should be carried on in the same general manner as the inspection of parts produced on a large-quantity basis.

The assembling of small lots of machines usually involves

a considerable amount of fitting. For example, all the small holes are not drilled in the larger pieces until assembly. Small brackets and similar parts are then clamped in position and the holes for their holding screws, dowels, etc., are located from them. Sliding members are scraped to fit each other, and to correct their alignment. This requires a certain amount of machinery on the assembling or erecting floor and also the services of skilled mechanics. However, as much of the machining as possible should be completed before the parts reach the assembling department. In most cases, this requires the provision of special manufacturing equipment and gages. Thus, as the quantity of the production increases and more and more special equipment is furnished, less fitting at assembly is necessary. After the machines are assembled, they should be carefully tested for alignment, backlash, etc., and when possible, they should be actually tried out on work of the character they are made to perform. This last is the crucial test because upon its results the success or failure of the mechanism is judged.

CHAPTER XIII

SERVICE FACTOR IN INTERCHANGEABLE MANUFACTURING

In the final analysis, no manufactured machine or device is ever purchased for itself alone, but is acquired for the purpose of securing the service which it is supposed to render. Thus, for example, the purchase of a reamer is the purchase of reamed holes of a desired quality or standard. Consequently it follows that the reamer which produces the most reamed holes of the required accuracy at the least ultimate cost is the best reamer and is finally recognized as such. Its first cost may be higher than others, yet if it produces more holes during its life, or produces them more quickly or with less power, the average cost of the reamed holes may be much less than those produced with a cheaper tool. In like manner, the purchase of a machine tool represents the purchase of machined surfaces; the purchase of a typewriter, typed letters; the purchase of a sewing machine, sewn seams; of an automobile, transportation, etc.

The ultimate test of any manufactured article is the test of service. The component parts may be absolutely interchangeable, the manufacturing processes may be developed to produce large quantities economically, and the inspection may be as rigid as possible; yet if the required service is not rendered, all of this work is useless.

Preparing Functional and Manufacturing Designs. If a commodity is to give satisfaction, this service must be built into it at every stage of its development and manufacture. The first conception of a new mechanism develops from the realization of some service to be performed. The functional design of this mechanism is solely the development of some mechanical means of performing this service; this thought is paramount and every other consideration is subordinate to it. It is only after this re-

sult has been obtained that any great thought is given to the matter of producing the mechanism commercially.

The primary purpose of the manufacturing design is to develop the functional design into one which can be economically manufactured; yet, at the same time, the greatest care must be exercised to maintain all the serviceable qualities of the original design. The factor of economical manufacture must never be the controlling one when economy is secured at the expense of service rendered. The customer is purchasing this service, and any action which may rob him of some part of it is unjustifiable. The development of the correct manufacturing design is a long process. There are no laboratory tests which will show all the requirements and results of service. The largest part of this information must necessarily come from the study of the results obtained from the commodity when in actual service.

A large amount of this information can be readily secured if proper attention is given to every complaint from customers. Too often, information from such sources is treated as an annoyance to be smoothed over rather than as a definite problem to be solved or as a matter which is of far more value and importance to the producer than to the customer. In general, a complaint from a customer results from one of three causes: First, some faults in design, workmanship, or material may exist in the mechanism which prevent it from giving the service which is due the customer. If this is the case, prompt steps should be taken to correct the trouble at its source. Obviously this matter is of more importance to the producer than to the user if he hopes to remain long in business. Second, the customer may not thoroughly understand the handling and care which the mechanism requires. In such cases it is of the greatest importance to the manufacturer that the customer obtains the needed information, or else the reputation of his product will inevitably suffer.

The third complaint is usually due to the customer's attempt to perform work for which the product was not intended or which is beyond its capacity. It is essential that the manufacturer know the limitations of his product. Furthermore,

information derived from complaints of this sort often leads to modifications of the product which greatly increase its field of usefulness. Complaints of all sorts should be carefully checked and acted on accordingly. Several manufacturing concerns have a man or division in their engineering department that investigates all complaints from customers, using the information so gained in the improvement of their product. Only by such knowledge of actual results obtained under many conditions can the maximum service be built into a product.

Keeping Specifications up to Date. The specifications should include all information which is needed to produce a commodity capable of giving the desired service. In whatever form they are kept, they should be constantly revised to keep abreast to the needs of service. For example, if the material specified for a certain part proves too weak in actual use, it must be altered. Thus, the part may require a stronger material, a different kind of heat-treatment, or a strengthened design. Often it may be found that the original requirements of many surfaces or parts are not the correct ones. All of this information, if kept in such form that it is always available, will be found invaluable in the development of future products; products which will contain from the start a higher quality of service than any of the preceding ones.

Planning Production to Obtain Requisite Service. Every part of the manufacturing equipment provided should be selected or designed with the object of producing parts capable of rendering the required service. The design of the commodity itself, if properly recorded on the drawings, will emphasize these points; yet a careful check should be made to insure that no vital factor has been overlooked.

The constant care which must be exercised in every stage of the actual production determines in a large measure the character of the service delivered. No operation is too unimportant to be neglected. This care, however, must be taken by each individual workman. To obtain the necessary cooperation, every effort must constantly be made to develop in each workman the spirit of true craftsmanship. A craftsman. in the opinion of the writer,

is a man who takes pride in the work and skill of his hands and brain; who feels that each result of his labor is a monument to himself; and whose enthusiasm and consciousness of power prevent him from doing any work but his very best. No man can do justice to his own capabilities unless he is interested in and proud of the results of his labor. The manufacturer must realize that he should have a vital interest in the proper training of each one of his workmen, and should use every means in his power to foster true craftsmanship in all branches of his establishment. No part of any work is too elementary to justify such an attitude.

Inspecting Parts to Insure Service. Every inspector must keep in mind at all times the requirements of service which the parts under inspection must render. This service is the sole purpose for which the parts are made. If they will render it, the parts are correct; if not, they are incorrect. In a well-balanced organization, the inspection is not carried on to discover the faults which others have committed, but rather to protect the customer and the firm's good name as well, by guarding against the possibility of faulty work going out despite all precautions taken in the productive departments. Yet, even with the most rigid inspection, some flaws remain hidden and are not discovered until the commodity is in the hands of the customer. With an honest inspection, such occurrences will be the exception, but without proper safeguards, these occurrences are apt to be the rule, and the customer will soon learn it, to the disadvantage of the manufacturer.

The majority of mechanical products are tested on work of the type they are built to perform, before they are shipped. Needless to say, no attempt should be made to favor the commodity in such tests. Every effort should be made to detect any faults, and each fault detected should be permanently corrected. The interest of the manufacturer in the commodity should not cease when it reaches the customer. It is of more interest to the manufacturer than to the purchaser to see that his product is employed on the work it can best perform, and to see that it performs its maximum service. By so following up his product, he not only makes a satisfied customer but also

creates new markets for his product. Furthermore, as noted previously, the information gained by observing his mechanisms in service under many varying conditions will be invaluable to him in developing and improving his product, as well as often pointing the way to the development of new products.

Manufacturers in a number of different lines have established well-organized service departments, with a view to insuring that the machines or devices that they build will give the highest possible service and satisfaction to their customers. Such service departments are well known in the automobile and typewriter fields, but similar departments, somewhat different in their nature, on account of the varying conditions under which the product is used, are also found in the machine tool field, where some manufacturers have highly organized service departments for determining the best conditions under which the customer's work may be performed. Through such service departments it has often been found possible to increase greatly the output of the machines built.

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